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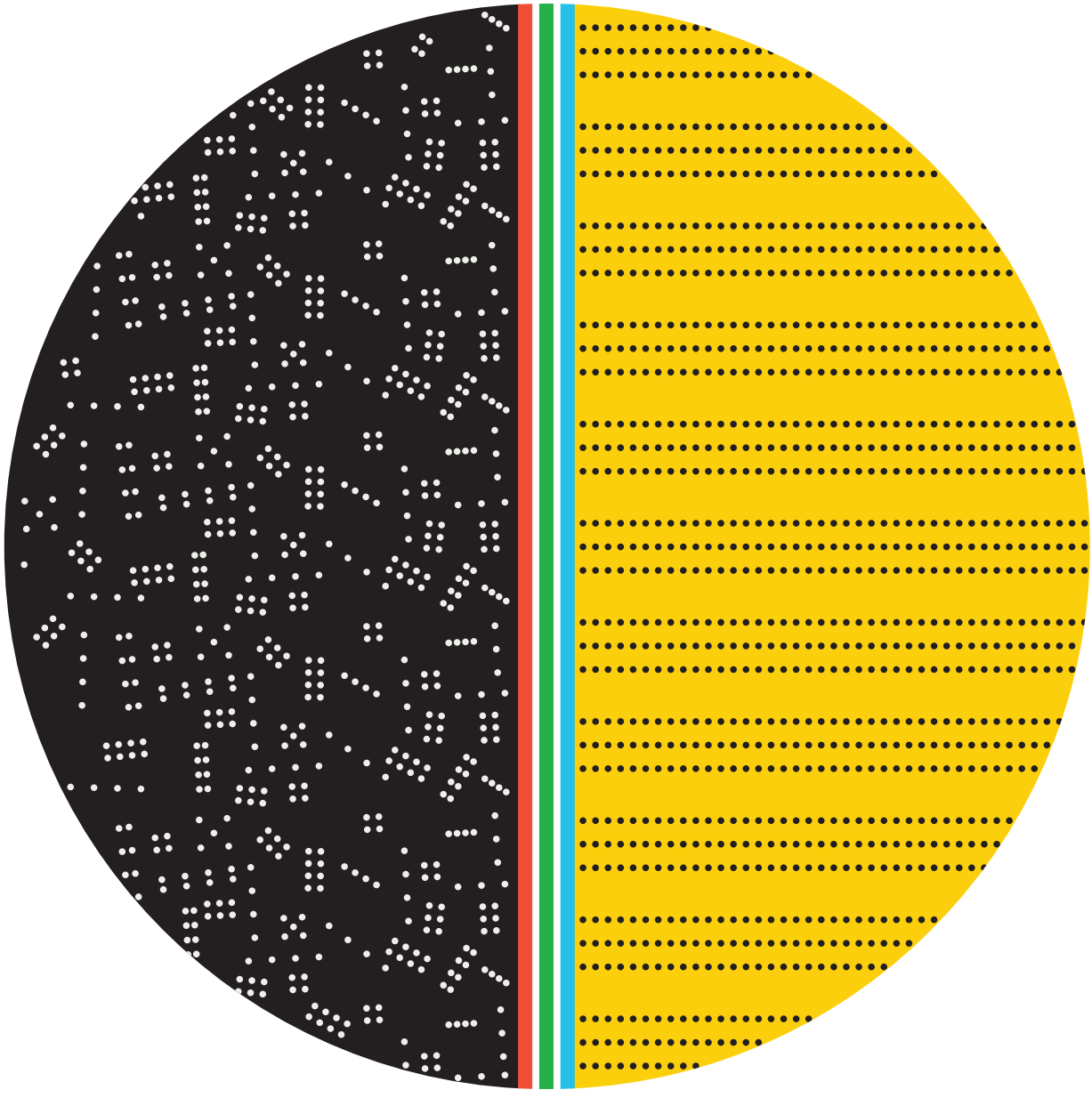

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CONTRIBUTORS

CHARLES GRAEBER profiles Kevin Fu, the TR35 Innovator of the Year (*p. 44*). Fu, an assistant professor at the University of Massachusetts, Amherst, studies ways to prevent hacking of credit cards and medical devices that use radio frequency identification. Says Graeber: "I was interested to learn that implanted defibrillators are tested by essentially triggering a heart attack in the operating room. It makes sense, and yet it's somehow shocking. I think Fu found this as surprising as I did. After his surprise wore off, he took that information and tested whether a bad guy could use it against the patient to create heart attacks rather than correct them. It's just another example of how his observational skills and his curiosity dovetail into his work as a technological innovator." Charles Graeber is a National Magazine Award–nominated writer and a contributing editor for *Wired* and *National Geographic Adventure* magazines. He writes for the *New Yorker*, *New York*, the *New York Times*, *GQ*, *Vogue*, *Outside*, *Men's Journal*, and others.

ELIZABETH SVOBODA writes about TR35 innovator Michelle Khine (*p. 54*), who came up with a deceptively simple idea that could lead to faster, cheaper medical tests: she uses a children's toy to make serious devices designed to be used in medical diagnostics. "I was especially intrigued when I heard I'd be interviewing Khine, a researcher who figured out a way to make complex microfluidic devices out of Shrinky-Dinks," says Svoboda. "Khine proved to be as down-to-earth as her practical invention makes her seem. When I visited her lab at UC Merced, she was in the midst of moving to UC Irvine, but she managed to keep a few of the Shrinky-Dink chips out of storage to show me. Khine's innovation proves that there's a lot to be said for good old-fashioned ingenuity as well as the use of practical workarounds—even in the most rarefied of disciplines." Svoboda is a freelance science writer based in San Jose, CA. She contributes to *Popular Science*, *Discover*, *Psychology Today*, and *Salon*.

CORBY KUMMER writes about the newest trend in California winemaking: biodynamic farming (*"In Vino Veritas," p. 102*). "I had no idea *biodynamic* was more than a fancy name for *organic*. And I certainly didn't know how strongly people would feel about whether biodynamic farming was actually better or just another California fad," says Kummer, who visited Sonoma County and Napa Valley to talk to winemakers. "A lot of what I heard is easy to make fun of," he says. "The fertilizers that biodynamic farmers use—they call them 'preparations'—sound like they're out of some medieval apothecary, or *Macbeth*. But the underlying principles—rebuilding the soil, and thinking of it as a kind of base crop you have to replenish and feed—are sound, even if some of the jargon sounds ridiculous." Does the wine taste any better? "Maybe," he says. "But the wineries certainly look lusher." Kummer is a longtime editor and writer for the *Atlantic* and the author of *The Pleasures of Slow Food*.

STEVE MOORS photographed Fu and Humanitarian of the Year (José Gómez-Márquez, p. 58), whose work on simple yet novel devices could improve health care in poor countries. "My shoots tend to be a little unconventional, and a few subjects will draw a line," says Moors. "Not these guys: they wanted to have fun. They bravely embraced the adventure and made themselves very much a part of the process." Moors is British but has lived and worked in New York since 2000. His work has appeared in *Face* magazine, *Tatler*, *Blueprint*, and the *Sunday Times* magazine.

GABRIELLE ALLEN (GRAEBER)

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TECHNOLOGY AND STIMULUS

In his second of two features on technology funding in the federal stimulus bill ("Chasing the Sun," July/August 2009), David Rotman examined the impact that government spending will have on the future of solar power by reporting on a plan to turn land in Chicago into the nation's largest urban solar plant.

David Rotman gave a good analysis of large-scale solar energy production, but analyzing only the up-front cost of a new energy production facility doesn't address whether the investment is sound. The correct method uses life-cycle costing (LCC), which factors in the life of the installation and the ongoing maintenance. The article also overlooks low-temperature geothermal as an alternative energy source. Low-temp geothermal combined with a heat pump is the most efficient form of heating and cooling and could reduce our peak electricity demand. The stimulus bill, which provides for tax credits for both, could make a real difference.

Rick Clemenzi
Asheville, NC

The article provoked much discussion online. One commenter approved of using solar cells but disagreed with Chicago's use of land.

www **Much better to place solar on all of the roofs in the US that are used solely for keeping the rain out. The trees growing on the site should be measured for their greenhouse-gas sequestration potential!**

Kevin Brown on 7/3/09
Kimberley, British Columbia

Another commenter wondered whether the first step toward reducing fossil fuel demand should be energy efficiency.

www **The article was a nice overview of solar energy, but isn't Chicago loaded with older houses that are energy inefficient? A landlord has no economic incentive to increase property cost to lessen the renters' energy cost. Wouldn't it be better to upgrade buildings so they use less energy?**

Carl Hage on 6/24/09
Sunnyvale, CA

NUCLEAR WASTE IN AMERICA

Chief correspondent David Talbot interviewed Allison Macfarlane, a geologist at George Mason University and a leading expert on nuclear-waste removal, who recently sat on a National Research Council committee evaluating the U.S. Department of Energy's nuclear-power R&D programs (Q&A, July/August 2009). One reader found Macfarlane's remarks unhelpful.

July/August '09

To read Ms. Macfarlane's responses, one would conclude that the entire project was political and the science is bogus. Though politics were involved, many respectable scientists have studied the site and drawn the opposite conclusion from Ms. Macfarlane. And her response when asked to name a more suitable location—"I haven't studied anything in detail, and I don't want to get anybody upset"—is the kind of nonanswer mumbled by politicians, not scientists.

Rick Kossik
Sammamish, WA

Another reader also framed the issue in political terms.

The political realities are simple: President Obama and Senator Harry Reid are trying to preëmpt the licensing review being performed by the Nuclear Regulatory Commission. If the NRC finds that Yucca Mountain is safe for Nevada, why should the country spend billions of dollars and take decades to look for an alternative that may be safer?

Abe Weitzberg
Woodland Hills, CA

A POUND OF CURE

Former Wall Street analyst Andy Kessler reviewed stimulus funding for electronic health records ("A Pound of Cure," July/August 2009) and concluded that the financial structure of the medical industry impedes their progress.

As a physician, I know that medicine's financing structure is an obstacle to IT benefits. While electronic medical records sound like a solution, most physicians still operate in small businesses. My practice is initiating an electronic records system, and we're seeing costs rack up already, making me think I've made the worst business decision of my career. Even patients don't see health IT as being in their best interests, since it can limit expensive tests and raise privacy concerns. Yes, medicine's financing structure creates impediments for IT, but for complex reasons, not because of "a misplaced desire to protect the lucrative status quo." If only the problem were that easy to fix.

David York, MD
Coeur d'Alene, ID

APPLES TO ORANGES

David Talbot ("Search Me," July/August 2009) describes a Wolfram Alpha search revealing that on the day of Sir Isaac Newton's birth, December 25, 1642, the moon was in the waxing-crescent phase. Alas, it is incorrect. Alpha's lunar calculation was based on the Gregorian calendar, whereas the December 25 date is Old Style; on that day the moon was nearly full. This error has since been corrected.

Joseph Chapman
Boston, MA

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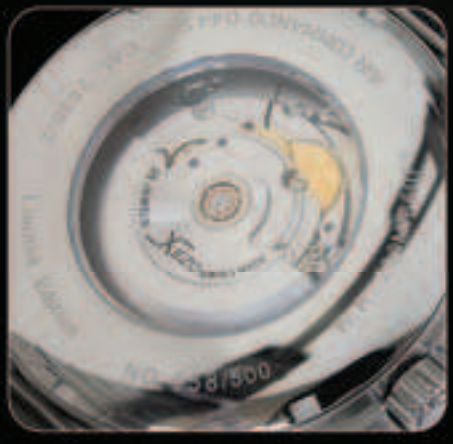

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NOTEBOOKS
Expert opinion

NATURAL GAS

Cleaning Coal

ACCORDING TO ANDREW PERLMAN, CONVERTING COAL TO NATURAL GAS IS OUR BEST STRATEGY FOR LIMITING CARBON DIOXIDE EMISSIONS TODAY.

The hot investments these days involve renewable-energy technologies that promise to generate electricity completely free of emissions, along with biofuels that promise to end global demand for coal and petroleum. Unfortunately, these technologies are not economically, technically, or logistically ready to be adopted on a large scale. Renewable energy will ultimately be a critical element of a more sustainable world. But if we have any hope of winning the battle against climate change, we must also focus on solutions that can have a bigger impact faster.

Burning coal is the single largest source of global greenhouse-gas emissions, and coal is not going to go away anytime soon. It is by far our largest energy resource—Illinois alone has more British thermal units (BTUs) of coal than Saudi Arabia and Kuwait combined have BTUs of oil. Coal now meets 50 percent of U.S. electricity needs, and its use in countries such as China and India is growing. Clearly, we need to find a way to use coal without generating harmful emissions, as an interim solution to one of the biggest threats to society.

One option is to convert coal into natural gas. Natural gas is made up of four parts hydrogen to one part carbon, and it is so clean we burn it in our homes without even needing a vent. A vast pipeline infrastructure already exists to move it around the country, and it burns extremely efficiently. Burning natural gas made from coal in a modern power plant generates about 60 percent less in greenhouse-gas emissions than burning coal directly and eliminates almost all other pollutants. Converting coal into natural gas has long been too expensive to implement on a large scale. But GreatPoint Energy, a company I founded in 2005, has developed a process called catalytic hydromethanation, which can economically convert coal into pure natural gas while removing and capturing most of the carbon.

Generating half our power in a way that releases 60 percent less carbon is not perfect, but it is far better than most other solutions I have seen. In fact, apart from nuclear energy—which comes with its own problems—I do not know of an option that could make such a significant global impact using available technology. Bear in mind that the U.S. Department of Energy's Energy Information Administration anticipates that renewables will account for only 13 percent of power generation by 2030, even at very aggressive buildouts.

In this economy, we have limited opportunities to bring to market new technologies that solve our environmental problems. It is up to the entrepreneurs and technologists to exploit the opportunities that exist, make our ideas work, generate returns for investors, and serve the planet. TR

ANDREW PERLMAN IS COFOUNDER, PRESIDENT, AND CEO OF GREATPOINT ENERGY. HE IS A MEMBER OF THIS YEAR'S TR35.

BATTERIES

A Consumer Revolution

OUR COLLECTIVE DEMAND FOR ENVIRONMENTAL RESPONSIBILITY HAS STIMULATED THE MARKET, SAYS CHRISTINA LAMPE-ONNERUD.

With some purchases, like a vacation home or a new car, consumers have long assumed that they should evaluate the total cost of ownership over time. But more and more people shopping for all kinds of things—food, clothing, travel. electronics—are now considering the total cost not only to themselves but to society. In fact, a host of innovative new products aim to reduce our overall costs and protect the environment at the same time. Many so-called green choices, even when they come at a small premium, actually save us money in the long run,

NICK REDDYHOFF

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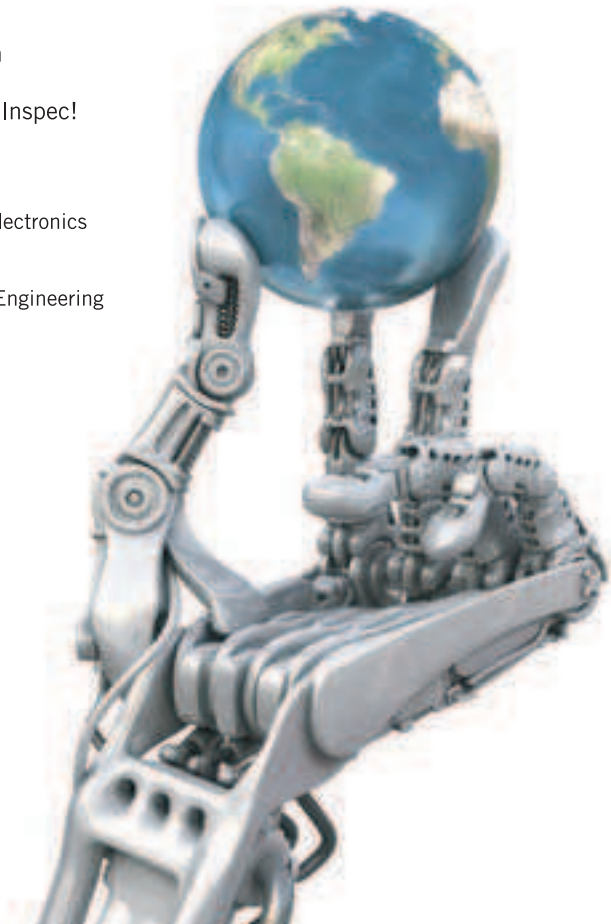

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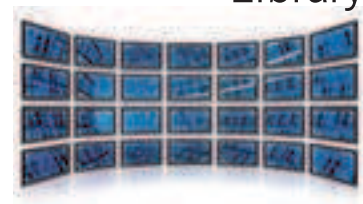

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because they last longer. I am inspired by this new wave of innovative products that deliver on their promises and are good for the earth.

Companies like Better Place, the Body Shop, and Whole Foods were all founded on the belief and trust that consumers would be willing to pay a little more for high-quality, ethical products. And their success shows that given the choice, many consumers will decide to help society, the environment, and, in the long run, themselves. We founded Boston-Power to produce lithium-ion batteries on that principle, too.

Consumers tend to buy computer batteries on the basis of their initial capacity, only to be disappointed when that capacity shrinks by half after just a few months. We decided that our first notebook-computer battery, designed to run four to five hours between charges, should retain its capacity for three years without degrading. Consumers would be able to buy just one instead of many batteries over the life of the computer.

That translates into a lower total cost of ownership for the computer, saving consumers money. Moreover, when fewer batteries are purchased, fewer are manufactured. Fewer manufacturing materials are consumed, less energy is needed for production and transport, and fewer goods must be recycled or disposed of.

As consumers, we are faced daily with decisions that affect the world around us. To save money and reduce our effect on the environment, we can ride a bicycle instead of driving a car, buy longer-lasting light bulbs, use high-quality electronics, and stop buying disposable water bottles. Each purchasing decision we make represents a choice and an opportunity for positive change. TR

CHRISTINA LAMPE-ONNERUD IS THE FOUNDER AND CEO OF BOSTON-POWER. SHE WAS A TR100 MEMBER IN 2002.

BIOFUELS

Biological Solar

COMBINING SYNTHETIC BIOLOGY AND SOLAR TECHNOLOGY COULD PROVIDE A WAY TO TRAP CARBON DIOXIDE AND PRODUCE FUEL, EXPLAINS DAVID BERRY.

By harvesting and burning fossil fuels, human beings essentially provide the tail end of a cycle hundreds of millions of years long. Plants and algae that grew by taking in carbon dioxide eventually turned into the deposits of coal and petroleum that we use to power our lives, rereleasing into the atmosphere the same carbon dioxide that nature had previously sequestered. Reducing these emissions will require us to change the way we think about both energy and carbon.

Reforestation is one tactic that has been broadly contemplated to mitigate rising levels of carbon dioxide; carbon capture and sequestration is another. These approaches close the carbon-energy cycle, but they have limited effectiveness in the near term and are difficult to implement on a large scale. Options such as corn ethanol, cellulosic biofuels, and fuels produced by algae offer a way to shorten the cycle: feedstock is grown for several years and then converted to ethanol or diesel. But these processes require input energy, typically from fossil fuels, and are therefore an imperfect solution.

There is a better way. A handful of projects—including an effort by Craig Venter's energy company, Synthetic Genomics—are now under way to use genetically modified photosynthetic organisms to generate fuels with input energy from the sun.

One such effort is Helioculture, an emerging technology pioneered by Joule Biotechnologies of Cambridge, MA, which can uniquely convert sunlight

and carbon dioxide directly into a range of fuels and petroleum-derived chemicals that do not require any additional processing steps. The process consumes no fresh water or agricultural land. But while the organism is important, it is not sufficient. Photosynthetic organisms engineered to produce ethanol or other fuels are grown in special chambers shaped much like solar panels, where they absorb sunlight and generate liquid fuels rather than electrons.

Unlike solar energy from photovoltaics, which depends on costly batteries for storage, fuels are efficiently stored in barrels, simplifying distribution and demand management. And because the technology used to grow the organisms is modular, it is easy to scale up. Joule is now gearing up to build a pilot plant in the southwestern United States. I believe that this new fuel source can feasibly replace the 289 billion gallons of gasoline per year that the United States is projected to need in 2050, and it can be produced in an area about the size of the panhandle of Texas.

Technologies of this kind promise a path to true energy independence, enabling us to reduce, or at least stabilize, carbon-dioxide emissions while supporting the power-hungry society we have created. TR

DAVID BERRY IS A PARTNER AT THE VENTURE CAPITAL FIRM FLAGSHIP VENTURES AND A COFOUNDER OF JOULE BIOTECHNOLOGIES. HE WAS THE TR35 INNOVATOR OF THE YEAR IN 2007.

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On Openness

WHAT FREEDOM ATTRACTS.

Openness is a virtue. When we like a person, we say, "She has an open face." About a friendly gesture, we remark, "That was openhanded." About ourselves when young, we might sigh, "I was open to new experiences." Openness is attractive.

Most technologists find openness attractive too. A technical term originally derived from thermodynamics (where it referred to any system that interacted continuously with its environment), *openness* came to be applied to systems theory, and thence to software, where it initially had a very specific meaning: open computer programs and languages are those that have some combination of portability (that is, they can run within a variety of environments) and interoperability (which means they can exchange data with other software). They must also adhere to open standards, a term that is generally understood to refer to two related ideas: that the software should be free for use, and its source, or underlying, code should in some manner be defined by its community of developers and users. The operating system Linux is the best-known open software.

The Windows operating system, by contrast, is closed, or "proprietary," in the jargon of information technology: it is not portable and possesses limited interoperability. Although elements of Windows adhere to open standards, the program must be licensed, usually for a fee, and its source code has been compiled and hidden from users and developers outside Microsoft. Developers write to application programming interfaces, or APIs, which until last year were mostly closed, and which still Microsoft jealously guards.

Ever since the emergence of the Web, whose multitudinous pages are themselves created with open standards, information technology has tended to become more and more open. Increasingly, software companies stress their openness. Often, this is mere marketing. Sun Microsystems' Java platform, widely used to create software for devices as different as embedded systems and supercomputers, has been portable and interoperable since it was launched, in 1995, but the heart of its source code was released only in 2007. Some perfectionist companies forswear openness because closed software can be more beautiful, particularly if it is married to hardware, like the Apple Macintosh operating system. But most technologists want their software to be open, because openness attracts innovation.

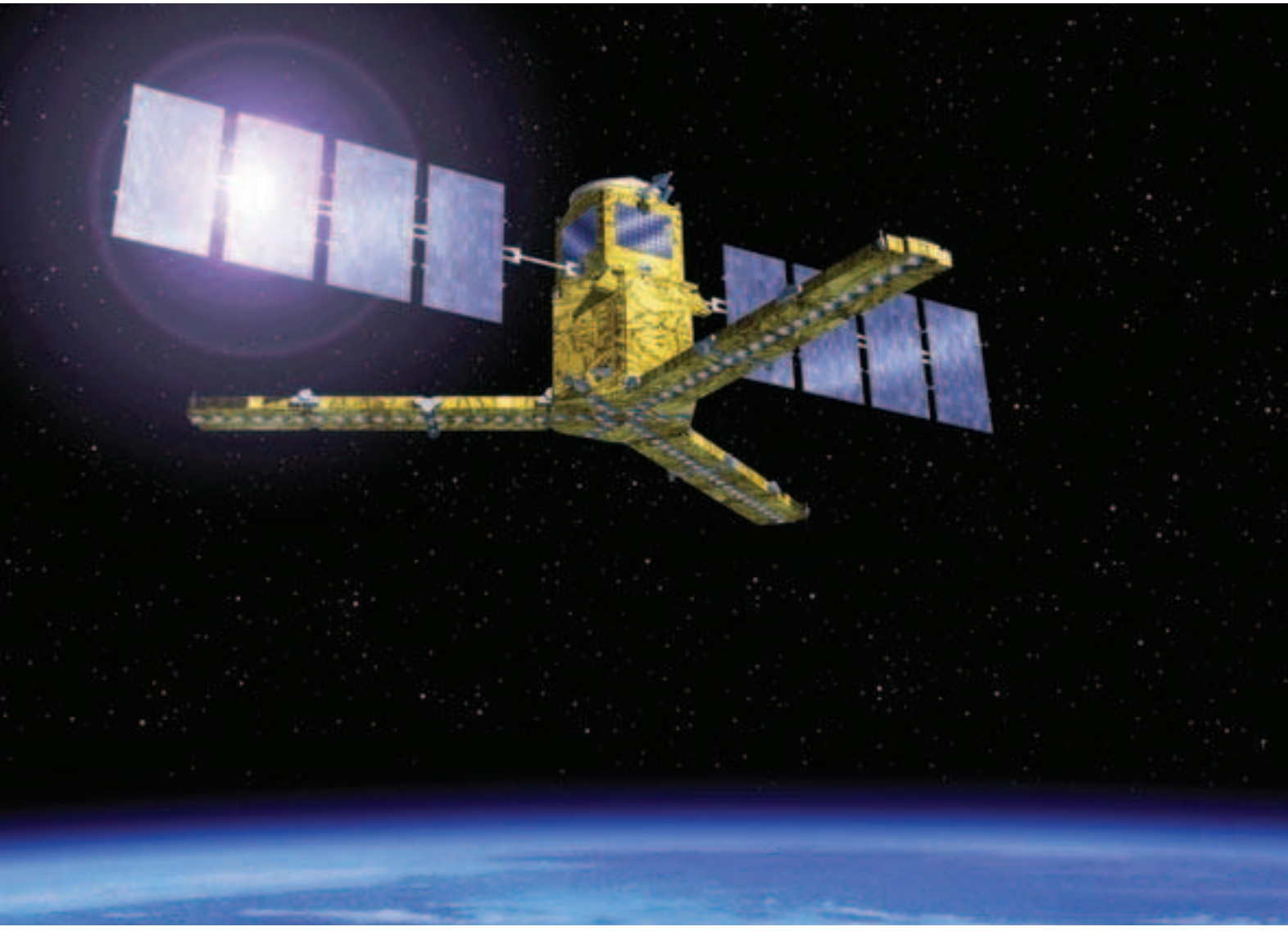
In this issue, *Technology Review*'s chief correspondent, David Talbot, describes the effort to make online video open *(see "OurTube," p. 72)*. He writes, "A growing number of technologists and video artists want to see Web video adopt the same openness that fueled the growth of the Web at large. ... A similar transformation of video would not just allow trouble-free playback of any video you might encounter. It would also mean that any innovation, such as a new way to search, would apply to all videos, allowing new technologies to spread more rapidly. And it would make it far easier to mix videos together and create Web links to specific moments in disparate videos, just as if they were words and sentences plucked from disparate online text sources."

The innovations such openness would encourage are impossible to predict. Talbot quotes Chris Blizzard, director of technical evangelism at Mozilla, which develops the open Web browser Firefox: "Nobody is going to tell you they want something before it emerges—rather, the experience of the Web is: 'Holy Cow, I can do this other thing now!' Open standards create low friction. Low friction creates innovation. Innovation makes people want to pick it up and use it."

Are there limits to the alchemy of openness? As these quotations suggest, the word has come to be used broadly of all creation that is collaborative and unbound from any one company and that favors free use over paying for something. Proponents of openness tend to assume that history is with them: they are sure that industries beyond information technology will successively become open. Some evangelists of openness believe that written media (the only industry I know as well as information technology and biotechnology) must become open too. To hear them explain it, open written media would be created by anyone, not just professional journalists; it would not be owned by any one publisher but would be endlessly replicated around the Web; and it would be free.

I wonder, though, how applicable radical openness is to written media. (To read my critique of WeMedia, see my "Manifesto" in the May/June issue and at technologyreview.com.) In one sense, written media is already open. Unlike some computer code, words are both portable and interoperable. Anyone who knows a language may use its words freely, and they can be understood by any other speaker. Words are their own source code. Yet some writing flourishes best when authors are paid and are supported by publishers that make money directly or indirectly from their audiences. Written media is closed in the sense that it aspires to a kind of formal perfection and is created by people who feel highly proprietorial about their creations. But write and tell me what you think at jason.pontin@technologyreview.com. —*Jason Pontin*

MARK OSTOW



DIGITAL FRONTIERS IN SPAIN

Spain's Telefónica has grown to become one of the largest telecommunications companies in the world. In addition to its focus on communications networks, it also develops technologies for health and education. The company is one of many Spanish success stories in the rapidly growing field of information technology and communication, as communications reach ever more distant corners of the world and innovations in computers, phones, and satellites facilitate an increasingly fast information flow.

SECURING THE DATA

In 2006 Spain introduced the country's first electronic identity cards, allowing its citizens to be in secure online touch with its government and health agencies. In what has become a reference point for other countries considering a similar move, participating Spanish citizens can use the cards to do things such as filing their taxes and checking their driving records online. Ten million Spaniards already own these new identity cards, and the government plans to expand them to all 40 million citizens in the next few years.

"The need for security for all these systems provides a competitive advantage to Spanish companies," says Jesús Banegas, president of AETIC, the Spanish Association of Information Technology and Communication Companies (Asociación de Empresas de Electrónica, Tecnologías de la Información y Telecomunicaciones de España).

"This is one of the biggest projects in the identity arena," according to Jordi Buch, marketing manager for the information security company Safelayer. Safelayer makes software to manage the digital certificates that ensure the safety of information encoded on the card.

IMAGE COURTESY OF MIER

The original Safelayer technology, created a decade ago, verified bank employees and customers, increasingly important after Europe implemented a digital signature law that allows use of digital signatures in place of physical ones. Safelayer captured approximately 80 percent of the Spanish market and expanded to Portugal, France, Morocco, and several countries in Latin America.

Safelayer's innovation, says Buch, lies in software that is easily integrated into existing applications. In the past, companies needed four to six months to integrate security, but "we have a technology that can do the same in one month," says Buch.

Carlos Jiménez formed an interest in virus detection early. In 1988, while he was a university student in Madrid, the Friday the 13th virus threatened university computers. Jiménez created a new method for protecting computers from viruses, monitoring for potential viruses while executing a program instead of when scanning a new disk. He gave his solution to the university for free. "At the time nobody told me to patent the technology: my first mistake," he says, laughing; he sent the solution gratis to other companies as well.

By 1990, when companies had come to him to detect more than 200 viruses, he realized it was time to form a company. Two years later, he opened an office in California. Software magazines recognized his original company, Anyware, for its new method for fighting viruses. "In 1998," Jimenez says proudly, "we were the second most downloaded antivirus software on the Internet."

In 1998, he formed a new company, Secuware, that approaches the problem from a different angle. Instead of detecting known viruses, the technology detects known applications. "It's like what my mother said when I was a child: 'Don't trust strangers,'" says Jiménez. "It's the same in the platform." Secuware also created a preboot operating system that protects Windows itself. While Windows runs, the system quickly watches and monitors, but it demands little power. This security operating system is in use by the Spanish tax service and the Bank of Spain, among others, and the company has expand internationally to count NATO, Warner Bros., and Walmart among its customers.

RealSec started out as a consultancy, providing original software and integrating third-party technologies. In 2003, RealSec began to focus exclusively on research for original products and technologies. The company received international certification for a hardware security module, an encryption device that meets the security needs of major credit cards, banks, and government institutions. Because it incorporates a tamper resistant layer, any manipulation of the device would cause it to automatically erase the information. It also has a digital key, stored on smart cards allocated to three people in the company who are unknown to one another. RealSec is selling these systems in Spain, in the US, and in a number of Latin American countries.

The founders of S21Sec also saw the challenges in Internet security a decade ago, and they took the question of how to protect companies from infiltration to those who should know the most about it: the hackers themselves. In 1999, the company's founders staged Spain's first hacker's conference in Mallorca. "It was interesting because it wasn't the usual community of security experts," says Igor Unanue, one of the founders.

S21Sec hired the best of the hackers and created a company in San Sebastian, in the north of Spain, to turn their skills into legal and profitable ones. S21Sec's founders had connections with a local bank, and the bank's CEO invited company engineers, all in their early twenties, to come and attack the bank's security.

Engineers took advantage of weak points in applications to infiltrate other supposedly secure systems. Says Miguel Rezola,

FROM THE CLOUDS

Twenty years ago, Panda Security founder Mikel Urizarbarrena had already created a number of software systems. One of them became infected with a virus that caused a ping-pong ball to drop down on the screen. In response, he started collecting viruses, simply as a hobby. But by 1990, Urizarbarrena realized that the hobby could become a business.

Today the company operates in more than 200 countries, with offices in 56. Panda Security's products focus on security through antimalware technology, protecting both consumers and businesses from viruses, spy ware, worms, and other Internet threats.

The company has launched many technologies since its founding. In 2004 Panda engineers created a program to identify viruses proactively. To do so, engineers investigated the behavior of a file to determine if it is legitimate or potentially a virus. Building on the 2004 software, Panda Security then developed a rapid method to automatically detect and disarm the overwhelming wave of malware. Instead of scanning against a signature file within a PC, which is known to slow computer operations, the information is sent to Panda's lab servers and scanned from what's known as "the cloud" against a database holding 29 million examples and growing of malware. This product can deliver quick antivirus services, taking advantage of the collective intelligence of millions of computers to stay up to date on viruses and malware without affecting PC performance.

Now Panda is offering this system free for personal computers. Cloud Antivirus was launched in the spring of 2009, and within just the first few weeks, the software received millions of downloads.

S21Sec's international director, "We'd show our customers a list of passwords and e-mails. We could get into a company in Spain and fill up planes with passengers, change the price of tickets, everything that involves attacking the infrastructure."

Today S21Sec specializes in anti-phishing and anti-malware software and rescues information that was stolen from customers. They also perform digital surveillance, trolling the Internet in a variety of languages, including English, Spanish, Portuguese and Arabic, to unearth all the information that the Internet provides on their clients' companies or issues.

Bernardo Quintero, founder of the security company Hispasec, says he never planned on founding a company, but his interest in computers began early. When he was 16, his computer became infected for the first time with a virus, "so I programmed a virus detector to prevent it from happening again."

"With the arrival of the Internet, I became interested in security in general," he says. He started by writing a column on security for a Spanish PC magazine. That turned into a website—Hispasec—which Quintero created with other experts in the field to provide daily updates on issues of Internet security. Hispasec's writers became national experts in the field, and companies began to request consultation and security audits from them, "so we were basically obliged to create the company to satisfy the demand," according to Quintero.

Hispasec engineers have developed programs to detect vulnerabilities, penetrate a company's information boundaries, and combat phishing and trojan malware that attempts to hijack computer systems. In 2004, they also developed a service called VirusTotal, a free service that allows the analysis of any file using multiple antivirus programs.

"With VirusTotal, we've classified more than 20 million examples of malware, and it continues to grow at an astounding rate," he says. This knowledge has brought the company unexpected benefits: says Quintero, "Because we have such a huge library of malware, we were able to become a specialized laboratory for trojan malware, which robs bank users of their personal information."

Security also played a key role in the development of Gesfor's Educa project, an online education management tool currently serving millions of users—teachers, students, and parents—in Madrid and in other regions around Spain. Gesfor, which provides IT services around the world, created Educa in cooperation with the local government to provide ongoing information about assignments, due dates, and grades, allowing parents and teachers to follow a student's progress. This project builds on Gesfor's experience managing information systems, human resources, and security for banks, airlines, and the tourism sector.

"Because Educa is used by a lot of young people, the security side of the project was also very important, and we're implementing security functionality that we've developed in house," says Jaime del Rey, Gesfor's chief technical officer.

CARING FOR THE SICK

Experience in security technology has provided the basis for many companies to expand into the growing health-care sector. Spain has universal health care, decentralized among its 17 regions. National identity cards are expected to facilitate the system's transfer to electronic records, and security is key in managing electronic health records.

But security is only one potential application for information technology companies in the health-care sector. A number of Spain's most prominent IT companies saw the burgeoning of computerized and online health-care management as a business opportunity.

Telvent, which specializes in information technology and services around the world, began branching into health care services five years ago. The original products included IT developed for health care, such as customer information systems; those systems have been applied to managing centralized health records of millions of people in Spain and in the Dominican Republic and are now being introduced in Chile, Peru, and Brazil.

> "The challenge here is to be able to connect and put in place the different processes for the providers of health-care services and the patient."

Telvent saw an opportunity to apply its experience in digital imaging to health-care specialization as well. The digital-imaging technology was originally developed for national identification cards in order to recognize patterns in documents and photographs and to screen noncitizens.

"For radiology, it's more or less the same. You have to work with graphic libraries in order to recognize certain patterns, such as diseases," says Adolfo Borrero, Telvent's health-care and public administration vice president. This imaging technology is in use in the Dominican Republic for telemedicine. Looking to the future, company engineers are developing three-dimensional software that will build an image from thin photo slices of a patient's body; the 3-D image will assist surgeons in planning operations.

Indra, another major Spanish IT company, has capitalized on its experience in managing transportation and traffic control to develop a health-care product that integrates all the information for a given patient within the health-care system.

The newest system also includes information on a patient's social and occupational life. "It's a complete health record, not just a clinical record," says José Cubelos, Indra's health sector director.

"Health-care expenses are growing, we have an older population, there's an increase in lifestyle diseases such as diabetes,"

Specially designed toughbook devices feature a lightweight, sterile, and portable interface for health-care environments.

PHOTO COURTESY OF INDRA

says Cubelos. "The challenge here is to be able to connect and put in place the different processes for the providers of health-care services and the patient." Healthcare 2.0, as Indra refers to its product, was developed following the company's experience implementing regional health-care systems for more than 18 million Spaniards. Indra is now delivering regional and countrywide health-care IT, including systems for hospitals and primary care, in Portugal's Azores Islands and in a Brazilian state of Acre; and the company is competing to deploy its system in Middle Eastern countries.

With previous expertise in creating simulations for flight training, Indra is now developing simulators for medicine, which can be customized for different specialties. Both Telvent and Indra are developing systems of intelligent devices in homes that will monitor the health of patients and facilitate doctor-patient communication.

Informática El Corte Inglés (IECISA), the information and communication technology subsidiary of the well-known Spanish department store, has also risen to a place of prominence in the development of information systems that serve as the backbone of health-care management. IECISA has developed national health-care IT projects that allow clients to efficiently manage health-care needs, primarily in purchasing and patient management. "Free public health in Spain involves many resources and a great deal of funds, and technology is a crucial part of it," says Miguel Angel Montero, director of health strategy for IECISA.

IECISA operates in many countries in South America and the European Union.

The idea for another new company struck Beatriz Ortiz and her husband Carlos Herreros upon the birth of their first child, Eva, twelve years ago. "My husband saw how they placed the identification tag on her ankle before taking her off to care for her fever, and he thought how easy it would be to change the tag," says Ortiz.

The company, Neonatal Custody and Identification (Identificación y Custodia Neonatal, or ICN) has created the first computerized neonatal identification system, a codifier with physical pieces that contain a unique identifying number for each new birth.

ICN has also developed a second layer of security to prevent baby thefts in response to customer requests from the United Arab Emirates and Dubai. All its ID now come fitted with radio frequency identification (RFID) tags. A baby removed from the hospital will cause an alarm to sound.

Yet a third level of security involves a method for recording neonatal fingerprints that ICN was the first in the world to develop. (The usual ink fingerprints are not detailed enough to use for newborns). In the delivery room, the attendant opens a computer file, reads the mother's codifier, and takes a photo of the mother's fingerprint. The baby's codifier is entered, and if it matches the mom's, a special camera opens to take photos of the baby's middle and index fingertips. The file is automatically closed and sent wirelessly to a control system.

Ortiz says it's a challenge to keep up with the demands of a new and rapidly growing company, but "it's more than a business for us. We're pushed by the thought that we're doing something necessary and important, which gives us a lot of joy."

TRANSMITTING THE SIGNAL

Spanish companies have taken advantage of the country's geography to devise solutions to digital television broadcasting challenges. In 1999, Spain became the first country to use a single-frequency network for digital television.

Due to the challenges of Spanish geography, with its many towns hidden in valleys between mountains, small transmitters with low power were needed. Though most major companies didn't bother to fill this niche, the Galician company Egatel devised low power transmitters. And so when in 1999 the national broadcaster requested bids for companies to provide transmitters for the upcoming digital television network, Egatel won 66 percent of the country's market share. They began to manufacture high-power transmitters as well, eventually winning the bid to provide transmitters for 90 percent of the digital coverage.

But with antennas transmitting on the same frequency, "you have a feedback from the transmitting antenna… So we developed software that cancels echoes, all the noise that you have when you transmit the signal from a receiving antenna to a new transmitter antenna," says Javier Taibo, international sales manager for Egatel. Today, many countries now use single-frequency networks, and Egatel sells its products worldwide.

Digital television products have proven to be a major success for the Spanish company Ikusi, located in San Sebastian. (Ikusi means vision in the Basque language). Founded half a century ago in a garage by Angel Iglesias, who still heads the company, Ikusi grew in its first few decades from a television installation company to a major manufacturer of reception and distribution equipment. Its research and development laboratory was founded in 1964, and "innovation has always been key," says Marco Domínguez, Ikusi's director of technology.

The company expanded from television communications into other sectors more than 30 years ago, and today it is an important player in the integration of networks and electronic systems for markets such as banking, airports, railway, road infrastructures, and security centers. A current research project named iToll involves the development of an intelligent toll system without physical barriers, which combines computer vision and electronic payment and—in the future—will integrate satellite vehicle-positioning systems. iToll will allow for the free flow of vehicles, which will no longer need to slow down for toll collection.

The potential for significant growth in mobile television has inspired additional research in that field. The company Sidsa, which designed and sells chips that allow what's known as "conditional access" in the boxes for cable or digital television, is

NANO COMMUNICATION

Premo has taken the idea of communication down to the nanoscale. The company has had success in designing products for the television, power, and communications sector. Their most innovative line for the future, according to marketing director Rocío Arrupe, focuses on radio frequency identification (RFID). Premo has designed tiny RFID antennas that, to take one example, measure a car's tire pressure and alert its monitoring system; Premo has captured 50 percent of this market. "Then we thought, we should make this smaller and cheaper — but instead of fighting to have smaller and more capable chips, let's just see if we can do it without electronics," says Arrupe. "As humans, we identify each other [but] not by a label, so let's identify particles or molecules that we can attach to an object that we want to identify."

Working with a university in Barcelona, the company has generated molecules, each with a distinct identity, to serve as markers for identity tags. Two products based on this technology are going to be in the market this year, one for an American automobile company to make its engines more efficient, and another for hospitals to tag surgical equipment.

looking to the potentially astronomical growth of mobile television. Engineers developed a bidirectional chip for television reception that both receives signals and returns them, useful for mobile handsets that receive a television signal and return the signal of their location.

And Sapec has capitalized on its audio processing experience to develop a range of products for audio and video compression that allow for accurate transmission while preserving bandwidth. "We're now working on new algorithms for better compression that will be useful for receiving television on your mobile phone," says Miguel Cristóbal, Sapec's managing director.

Televes, one of the largest Spanish manufacturers of antennas, amplifiers, receivers, and satellite dishes, has the biggest market share in Spain for in-home receivers and digital signal processors and sells its products in more than 50 countries around the world. In 2002 Televes created a system of transmitting signals through a house utilizing coaxial cable, the copper antenna cable used by TV companies. This system allows the company to use the cable for multiple services in a home or building to optimize telecommunications, integrating remote control, video surveillance, and data networks.

WIRING THE CONNECTION

Managing the explosive growth of the Internet and the demands this growth puts on traditional modes of communication interested the founders of DS2. Telephone lines provide one means of transmitting high-speed Internet. DS2 engineers thought: Why not use power lines?

"Telephones are technically easier," says Chano Gómez, vice president of technology. "They were installed for communications and are well maintained by the telephone company. Electrical wires, whose purpose is to transmit energy, are more challenging." But many applications could transmit information throughout a home or building using existing electrical wiring. "There are many appliances that connect to the electrical wires and generate noise, which makes it a greater challenge," Gómez continues. This technology, though, is potentially useful when computers demand high-speed hookups around a house — for downloading large files, watching television, or backing up data — and wireless routers don't offer enough speed or reliability.

DS2 developed a transmission system that utilizes different frequencies than electricity does. The company's chips use digital signal processing to recover the original signal, cancelling out all the noise on the line. A home's electric meter then blocks the Internet signal from being transmitted outside the house. Telefónica in Spain, major telecommunications companies in the UK and Portugal, and retail brands in the US that sell home networking solutions offer DS2's link as part of their solution.

DS2 sees yet more significant opportunities ahead as smart grids are developed. Utilities will need to receive real-time information on home electricity use. "Instead of having to go to homes every month to read a meter, this can be done remotely using electrical wires, with one of our chips in the electric meter," says Gómez.

COMPUTATIONAL VISIONS

The basic ideas of how computers can create graphics inspired Ricardo Montesa, CEO of Brainstorm. In the mid 1980s, when he was a student, computers could only generate text, not even a straight line. Then he saw a computer that could render a graphic, a black background with green lines. Soon after that, a visitor to the university gave a demonstration of the very earliest versions of computer graphics. "I fell in love with the technology," says Montesa.

Today, Brainstorm, born from Montesa's early efforts, creates graphics-building software that is key to European and American televised election coverage, rapidly integrating all new data and transforming it into visuals.

As the votes for Obama and McCain were counted at the close of the 2008 American presidential elections, audiences turned rapt attention to the red-and-blue tallies of votes and percentages that inched higher as the night wore on. Brainstorm created the graphics for NBC and has also created all the BBC's election graphics; the NASDAQ graphics displayed in Times Square; and all the virtual graphics for ESPN. ILM, a George Lucas company, bought the company's virtual set software for the movie *Artificial Intelligence*, and the software has since been used in other movies including *I Robot* and *X-Men Origins*. Today, Brainstorm is participating in European projects to develop games that will help marginalized youth and the elderly.

Victor González, one of the founders of Next Limit Technologies, describes creating his company with Ignacio Vargas when the two were students. They both enjoyed computer graphics and animation, and both were programmers. González and Vargas also noticed that a relatively easy and realistic rendering of fluid, as when waves crash, was missing from animation. "We thought there was a gap that we could fill in fluid simulation, that we could create those effects within a computer," says González.

The two men started applying what they were learning in engineering, designing computer graphics that can realistically mimic fluid dynamics on a computer, television or film screen. The partners developed a prototype of the software. Then they showed up with it at a visual effects conference in Orlando, "and people were excited about what we were doing," he says.

Next Limit Technology's software has assisted production companies for top-name movies such as *Lord of the Rings*, *X-Men*, *Charlie and the Chocolate Factory*, and, most recently, *The Curious Case of Benjamin Button*. In 2008, Hollywood's Academy of Motion Picture Arts and Sciences honored Next Limit with a technical achievement award.

Now the designers at Next Limit are bringing their technology back to engineers. They've created a program called XFlow, a fluid simulation software that is scientifically much more accurate than the one designed for Hollywood. "Our targets are the

Using software designed by Next Limit, special effects artists can simulate the fluid or air conditions surrounding cars, planes, and buildings with a high degree of accuracy.

engineering industry, those who need to simulate the fluid [or air] conditions around a building, plane, or car," says González. While other products are on the marketplace, they don't have the visual effects of XFlow, which capitalized on Next Limit's Hollywood experience and provides engineers a realistic visualization of their tests or designs. "We're excited to be at the top of a new technology," says González. "Our vision is that we can bring visualization and science together to create new paradigms for design and engineering."

The two brothers behind the company Zed founded the first Internet service provider in Spain, but they sold the original company to Telefónica. Instead, they focused on the content that major companies such as Telefónica could by then provide to customers.

In 1998, Zed's subsidiary Pyro Studios released Commandos, Spain's first internationally popular video game. At the same time, the company turned its sights on the growth of mobile technology, in 2002 creating a studio solely for mobile video games. Today the company offers 200 games on a variety of platforms through major international players such as Nokia Ovi Store and Apple's iPhone. "Right now we have contracts with 130 telecom operators around the world, reaching more than two billion mobile subscribers," says Miguel López-Quesada, Zed's manager of corporate communications.

The company's latest graphic offering builds on the success of their video games and mobile offerings, and on the recognition, according to López-Quesada, that "with digital entertainment, a video game with a ninja or a spaceship becomes incredibly popular in both India and Peru; it really is a universal language," he says. In response the company created a subsidiary called Ilion, dedicated to creating animated movies.

This year, Ilion is releasing Spain's largest production ever, an animated movie called *Planet 51*, with a Thanksgiving weekend release planned for more than 3,000 movie theaters in the U.S.

Zed also provides services. These include mobile services for banks and governments, such as mobile alerts the company developed for the health department in its home region of Valencia or the technological platform for mobile voting in Russia. They're also furnishing mobile content for the US National Basketball Association (NBA).

Zed's mobile phone content is also used by Telefónica, Spain's leading phone provider and one of the world's largest telecommunications companies. In order to foster innovation within the company, Telefónica has its own R&D company, which operates in five centers in Spain and two in Latin America and partners with more than 150 universities. In 2008 Telefónica started rolling out an optical fiber network in Spain to provide increasingly rapid connectivity, along with innovations in the digital television and mobile networks.

Current Telefónica research projects include the use of mobile technology to develop tele-education and e-health, including remote storage and reading of x-rays; remote diagnosis and rehabilitation; and applications to facilitate physician focus on patients.

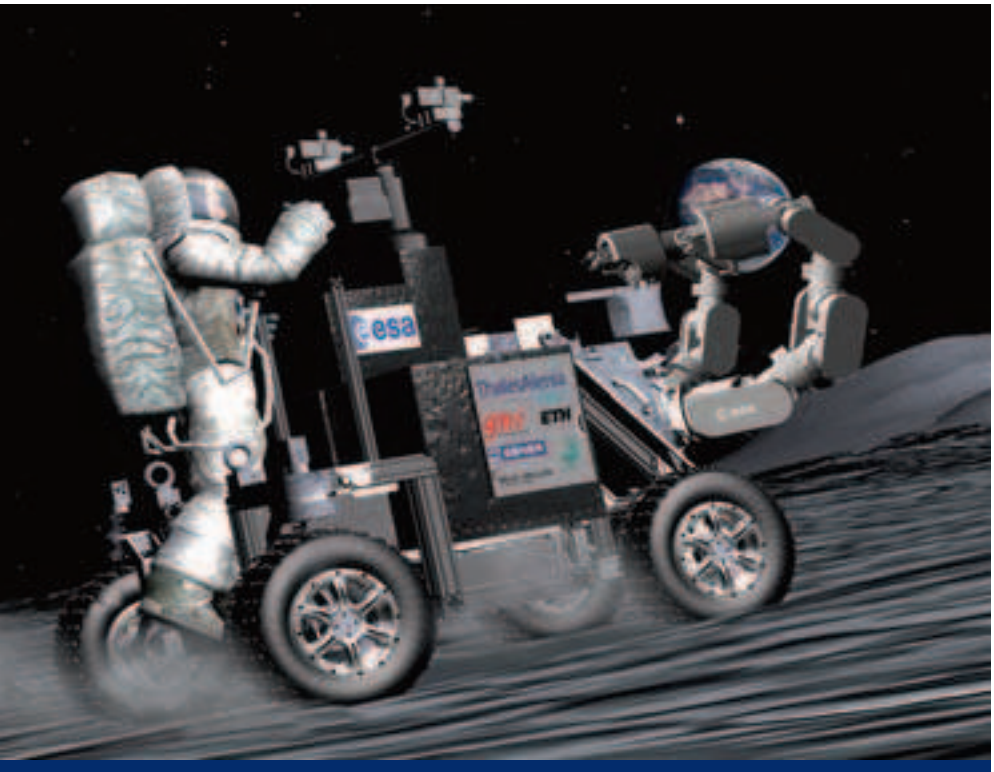
EXTRATERRESTRIAL COMMUNICATION

Expertise in antennas on Earth has led some Spanish companies to branch out into space. The company Rymsa was founded in 1974, specializing in antennas and today still has a successful terrestrial antenna business. In 1988, Rymsa began producing antennas that could broadcast from the first Spanish satellites. "From that moment on," says Andrés Nubla, head of Rymsa's space division, "we've participated in more than 200 satellites and have delivered more than 2,000 pieces for onboard activities."

The company developed antennas that help locate the satellite in the correct orbiting position for many customers around the world, including the European Space Agency and Lockheed Martin. They're currently developing antennas for the European Mercury launch. Temperatures on Mercury can soar to heights of around 400° or 450°C, which renders aluminum, the typical space-antenna material, unusable. Rymsa is developing prototypes made of titanium and silver plating for the launch.

Mier also began as a television antenna company, founded by CEO Pedro Mier's father and uncle more than half a century ago. Mier, then a university professor, began collaborating with other research groups to advance the company's technology. They looked to the upcoming digital TV revolution and

PHOTO COURTESY OF PICTORION DAS WERK



The EGP-Rover is a prototype of a vehicle for exploring the surface of Mars and the Moon. GMV's work, as part of a consortium of firms, will help facilitate space missions.

developed signal translators used today in Europe, the US, and around the world.

Mier engineers have also developed technology for low noise amplification for both communications and research satellites. This translates into the ability to reach a satellite from a small mobile handset, or for the satellite to receive and process scientific signals. In the Soil Moisture and Ocean Salinity (SMOS) Satellite, a project of the European Space Agency, sensors testing salinity in the ocean send information that Mier technology helps amplify and process.

The company is now combining expertise in space and terrestrial applications for hybrid television coverage—satellite coverage for rural areas in coordination with terrestrial repeater antennas for cities.

One company, GMV, has moved its operations in the opposite direction: from space to land. Founded in 1984 to support the European Space Agency in the analysis and design of missions, today the company is active in ground control and data processing for all types of satellites and for Galileo, the European global navigation satellite system. GMV recently moved into the American market and has customized a mission planning system for the Lunar Reconnaissance Orbiter, a new NASA back-to-the-moon mission launched in June.

"We've used our technology and expertise in space to meet the needs of what is today another significant part of the company, the transportation market," says Jesús Serranno, GMV's CEO, as the company is now one of the Spanish leaders in information systems that use satellites to coordinate buses and trains.

"Spanish companies are dynamic and creative," says Jesús Banegas of AETIC. "The Internet has changed the rules in information technology, and the most important aspect of a company is not its size. Instead, it's the ability to innovate and find solutions."

PHOTO COURTESY OF GMV

Resources

ICEX (Spanish Institute for Foreign Trade)
www.spainbusiness.com

AENTEC
www.aentec.net

AETIC (Spanish Association of Information Technology and Communications Companies)
www.aetic.es

GMV
www.gmv.com

INDRA
www.indra.es

PANDA SECURITY
www.pandasecurity.com

SECARTYS
www.secartys.org

TELEFÓNICA
www.telefonica.com

TELVENT
www.telvent.com

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TO MARKET

MEDICAL DEVICES

SLEEP ANALYSIS AT HOME

IF YOU'VE EVER wondered how much sleep you actually got during a restless night, a new home-use device may have the answer. Users sleep wearing a headband fitted with a sensor that monitors electrical activity in the brain. Physicians use similar data gathered from EEGs to diagnose sleep disorders, but EEG studies are usually conducted in dedicated sleep clinics. In the home device, the headband sends data wirelessly to a bedside unit resembling an alarm clock, which records and displays the user's sleep patterns. The data can be uploaded to a website that allows users to track sleep statistics and gives suggestions for how to improve sleep.

Product: Zeo personal sleep coach **Cost:** $400 **Source:** MyZeo.com **Company:** Zeo

JOSHUA SCOTT

PERIPHERALS

BUILDING A BETTER MOUSE

OPTICAL MOUSES freed us from mouse pads and the chore of cleaning gunk from our mouse's innards every few weeks. But they don't work well on transparent or highly polished surfaces. With its Performance Mouse MX, Logitech solves this problem by borrowing a trick from microscopic imaging: dark-field microscopy, often employed by biologists examining low-contrast specimens such as live amoebas. Unlike other optical mouses, which track their position by looking at the direct reflection of a laser that illuminates the surface beneath the mouse, Logitech's mouse ignores the reflection completely. Instead, it looks at the light scattered off minute imperfections and particles on the surface. This mouse works even on a glass desktop.

Product: Logitech Performance Mouse MX **Cost:** $100 **Source:** www.logitech.com **Company:** Logitech

ROBOTICS

From Battle Stations to Fire Stations

A SQUAD of three fire-fighting robots has successfully completed trials with the London Fire Brigade, becoming the first robots to be deployed with the third-largest fire-fighting organization in the world. Developed by the U.K.-based military supplier QinetiQ, originally for bomb disposal in Iraq and Afghanistan, the robots are being used in fires involving acetylene-gas cylinders, which present a grave risk of explosion. With such fires, everyone within a radius of 200 meters is normally evacuated for up to 24 hours. The new robots can clear a path through debris to the cylinders, determine how hot the cylinders are, and even hose them down to keep them cool, allowing evacuation orders to be lifted in three hours or less.

Product: Talon, Black Max, and Brokk 90 robots **Cost:** Undisclosed **Source:** www.qinetiq.com **Company:** QinetiQ

AUTOMOTIVE

WATCHING THE ROAD

THE LIMITED and SHO models of the 2010 Ford Taurus, which reached showrooms in July, feature an optional collision-warning system that has the first electronically scanned radar system to be built into a car. Manufactured by Delphi, the radar constantly switches between two fields of view: one that extends through 90° out to a distance of 60 meters (good for detecting objects coming in from the side, such as pedestrians) and one that extend across 20° out to a distance of 174 meters (for detecting targets directly in the vehicle's path). Previous automotive radar systems used multiple beams or required mechanical switching to achieve two fields of view, but the Delphi radar uses an antenna array, which relies on constructive and destructive interference of radio waves to shape the beam.

Product: 2010 Ford Taurus **Cost:** $32,000–$38,000 **Source:** www.delphi.com/4safe **Companies:** Ford Motor Company, Delphi

JOSHUA SCOTT (MOUSE); COURTESY OF QUINETIQ (ROBOT); FORD MOTOR COMPANY (TAURUS)

A SMART NEW WAY TO NAVIGATE

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ENERGY

HYDROGEN FUEL CELLS

Despite doubts abouts its feasability, hydrogen is finding its way into niche applications

Fill 'er Up

IN JULY, Shell opened New York City's first hydrogen fueling station for cars. Located at John F. Kennedy Airport, the station has a single hydrogen dispenser, available 24 hours a day. Currently, there is no charge to refuel: most users are expected to be participants in Project Driveway, a General Motors demonstration project for fuel-cell cars. Another refueling station is already in operation to the north of the city, and a second station within New York city limits is expected to open soon.

Product: Shell hydrogen fuel **Cost:** Free **Source:** www.shell.us **Companies:** Shell, General Motors

OPEN-SOURCE AUTOMOBILE

NOT LONG after the U.S. Department of Energy moved to end most federal support for fuel-cell transportation, the U.K.-based startup Riversimple has dived into the uncertain waters of the hydrogen economy with a tiny fuel-cell-powered car. The prototype of the hydrogen-powered vehicle is about the size of a golf cart. Though small, the body, made from carbon composites, is tough. Each wheel is powered by its own electric motor, and ultracapacitors store energy captured during braking. The car has a range of 320 kilometers and a top speed of 80 kilometers per hour. Riversimple is releasing the design under an open-source license. Its business model will be to lease cars to owners, with the cost of the hydrogen fuel included in the lease price. Owners will refill their cars at stations that Riversimple plans to build in urban areas.

Product: Riversimple hydrogen car **Cost:** N/A **Source:** www.riversimple.com **Company:** Riversimple

GERMAN ROADSTER

MERCEDES-BENZ'S B-Class F-Cell cars are racing—sort of—toward consumers. Twenty of them are being supplied to the city of Hamburg, Germany, as part of a municipal fuel-cell project. The cars have a range of 400 kilometers and a top speed of 177 kilometers per hour. The B-Class F-Cell was first announced in 2005 but has been slow to move into showrooms.

Product: B-Class F-Cell **Cost:** N/A **Source:** www.daimler.com **Company:** Mercedes-Benz

GEORGE TENNEY PHOTOGRAPHY (FUEL STATION); COURTESY OF RIVERSIMPLE (OPEN-SOURCE); COURTESY OF MERCEDES-BENZ (ROADSTER)

AP PHOTO/FABIAN BIMMER

HINDENBURG'S REVENGE

THE FIRST human-piloted hydrogen-powered aircraft, developed by the German Aerospace Center (DLR) and built by Lange Aviation, made a 10-minute maiden flight in July in Hamburg, Germany. Don't expect fuel-cell-based jetliners anytime soon; actually, the most likely ETA for such aircraft is never, since fuel cells have a power-to-weight ratio that makes large planes impractical. But the Antares DLR-H2, which uses a 25-kilowatt fuel cell, has far less lofty ambitions. It is a motor-assisted glider, capable of taking off by itself. Lufthansa Technik Group, an independent spinoff of the airline that focuses on aircraft repair and overhaul, will use the aircraft as a test bed. The company is looking ahead to a day when fuel cells will supply planes with onboard electrical power.

Product: Antares DLR-H2: **Cost:** N/A **Source:** www.dlr.de/en **Companies:** Lange Aviation, BASF Fuel Cells, Serenergy

PHOTOVOLTAICS

SHADE POWER

PHOTOVOLTAIC CELLS made from organic polymers, rather than crystalline silicon, could make solar power much cheaper. Last year Konarka, a startup based in Lowell, MA, opened a factory for such solar panels, which are flexible and produced in a process akin to printing *(see "Mass Production of Plastic Solar Cells" on technologyreview.com)*. The first application of Konarka's potentially transformative technology? Umbrellas. SkyShades, based in Orlando, FL, is incorporating the panels into umbrellas designed for outdoor seating areas in places like restaurants and bars. Patrons can recharge mobile devices such as laptops and cell phones from outlets built into the stem of the umbrella. The four-meter-wide Powerbrella can generate up to 128 watts of electricity, which charges a bank of batteries located in its base.

Product: Powerbrella **Cost:** Undisclosed **Source:** www.skyshades.com **Companies:** Konarka, SkyShades

STEPHEN ALLEN

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APC rack-based cooling offers cost-effective, future-proof solution

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Now you can get power, cooling, monitoring, and management components that easily deploy together as a complete, integrated solution. Everything has been pre-engineered to work together and integrate seamlessly with your existing equipment. Just slide this proven, plug-and-play solution into most existing spaces—there's no need for confusing cooling configurations or expensive mechanical re-engineering. The modular, "pay as you grow" design lets you be 100% confident that your server room will keep pace with ever-changing demands.

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APC takes the hassle out of configuring server rooms. Self-contained InRow cooling units, high-density NetShelter enclosures, and the APC rack air containment system combine to create a proper IT ecosystem in almost any surrounding. Rack-level monitoring sensors, intelligent controls built into the cooling unit, and integrated management software provide complete remote control and unprecedented visibility into the entire system. Simply add power protection (like undisputed best-in-class Smart-UPS or Symmetra units) and you have a total solution for today, tomorrow, and beyond.

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Q&A

ANEESH CHOPRA

The nation's first CTO explains how IT can reboot America.

When President Barack Obama announced the appointment of the nation's first chief technology officer, in April, he promised that Aneesh Chopra would "promote technological innovation to help achieve our most urgent priorities."

Chopra, who is 37 and was previously Virginia's technology secretary, recently spoke with *Technology Review*'s chief correspondent, David Talbot.

_TR_: Why do we need a national CTO?

Chopra: President Obama has suggested there is a role for technology and innovation across a wide range of priorities. While we have had White House leadership on technology policy in the past, this administration has taken a broader view of the power of technology to reduce health-care costs, deliver energy efficiency through smart-grid applications, and improve the skills of the workforce.

How does spending $10,000 to get broadband to a rural farmhouse help the economy?

It's not just broadband for the sake of laying pipe and capacity—it's about spurring innovative applications. We envision innovation in health care through telemedicine, distance learning, and even smart-grid infrastructure. One example of rural innovation we championed in Virginia was creating regional E911 services powered by broadband. And it is conceivable that a grant that supports a rural farmhouse would open up higher-wage tele-work opportunities to that resident.

What will make government smarter at promoting technology?

Government's role in promoting technology has traditionally been in investment for basic R&D or in the procurement of goods and services. It is my intention as CTO to focus on public-private collaboration to operate between those two extremes. In some cases, we might invest in a more targeted R&D opportunity that would bring private-sector resources, universities, and the public sector together on a given problem. In others, we might use a procurement opportunity to spur market innovation.

How would that work?

For example, Defensesolutions.gov is a website that seeks to drive innovation toward Department of Defense needs. Instead of procuring a specific device described by a multithousand-item specification, the department asks for a solution: "How do you field-test for the presence of explosives, drugs, and gunshot residue?" By leaving room for disruptive technologies in the private sector, we can procure an innovative solution.

That might find you a disruptive technology—but on health IT, aren't there plenty of established technologies?

Yes, but to receive stimulus funds, health-care providers will have to demonstrate meaningful use of technology to improve care quality, lower costs, or improve patient engagement and communication.

Is "meaningful use" an idea that should be more broadly applied?

I would love to see this model apply in other areas where we see policy benefits in the adoption and use of IT.

On the smart grid, power utilities might prove meaningful use by showing reduced electricity demand. But decisions are left to state regulators and local utilities. Will you fix this?

The federal role there has been very clear. First, we are seeding capital investment in this space through the Recovery Act—$4.5 billion for matching funds and demonstration projects. These initial projects are crucial to proving the value of the smart grid. Once the business case has been demonstrated, we believe that state and local decision makers will continue investing in the build-out. Second, we are working through NIST [the National Institute of Standards and Technology] on open standards to ensure the interoperability, reliability, and security of the smart grid. As we saw with the Internet, open standards enable innovation and scalability.

Can you tell us what a new national innovation policy might look like?

The administration has three key goals for strengthening America's competitiveness. The first is improving the environment for private-sector innovation. This includes efforts to make the Research and Experimentation Tax Credit permanent, to encourage small businesses with targeted capital-gains-tax reductions, and to reform our patent system.

Second, we must invest in the building blocks of innovation, such as human capital, fundamental research, and infrastructure. The president has committed to double the budgets of key science agencies, triple the number of National Science Foundation graduate research fellowships, and improve public-school performance in science and math.

Finally, we must harness innovation to address key national priorities, including accelerating the transition to a low-carbon economy, allowing Americans to lead longer, healthier lives, and making government more open and transparent. TR

Photograph by DAVID DEAL

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PHOTO ESSAY

Surface Restoration

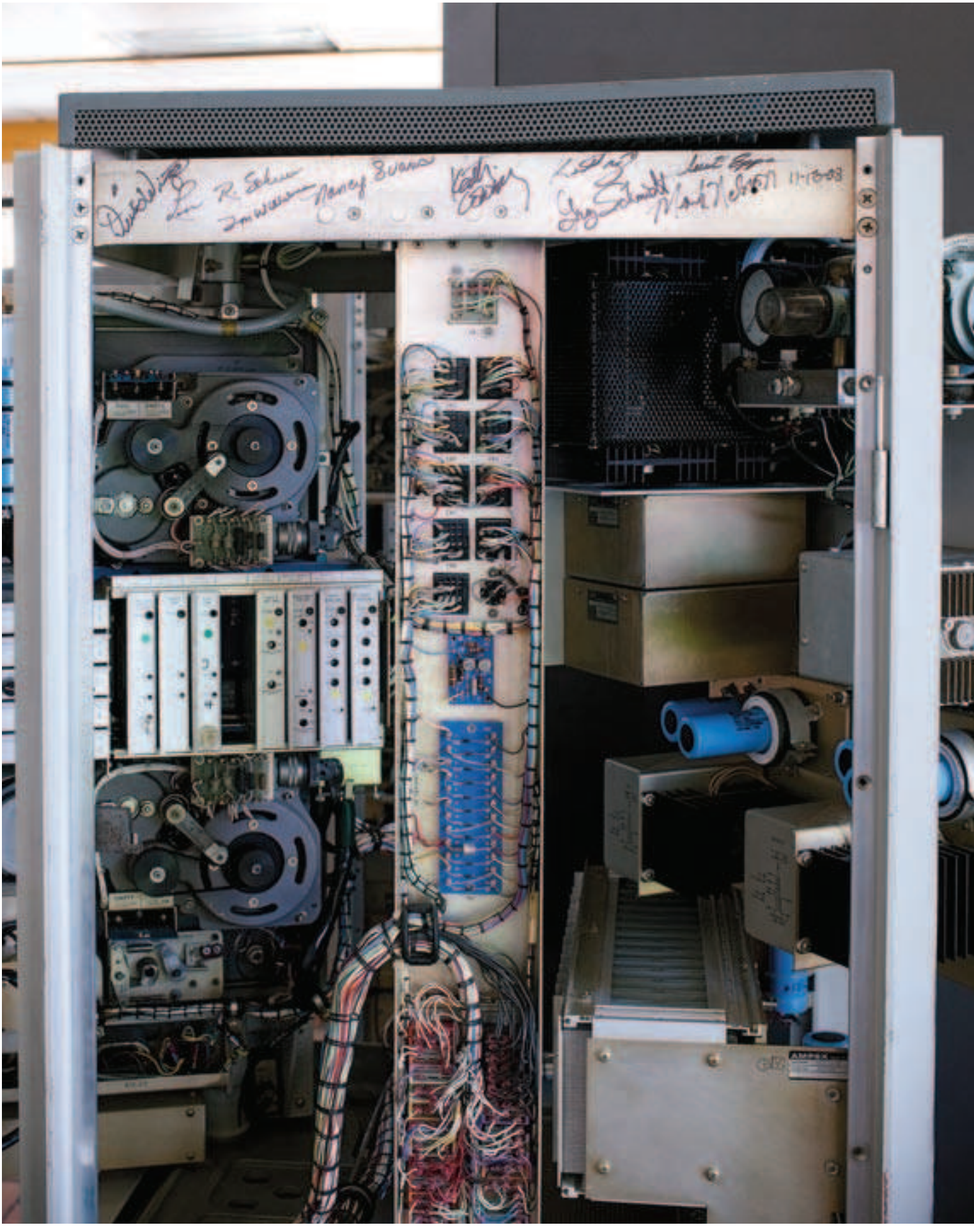
The images of the moon's surface taken by five NASA Lunar Orbiter satellites in 1966 and 1967 are still among the most detailed ever made. The original analog data, beamed down to Earth to plan landing sites for the Apollo missions, was recorded on magnetic tapes that collected dust for decades and were nearly discarded. Now a team of engineers at an abandoned McDonald's at Moffett Field in Sunnyvale, CA, is processing the data using restored and custom-built equipment, enabling a public that saw only snapshots of these historic images to view them at their full resolution for the first time.

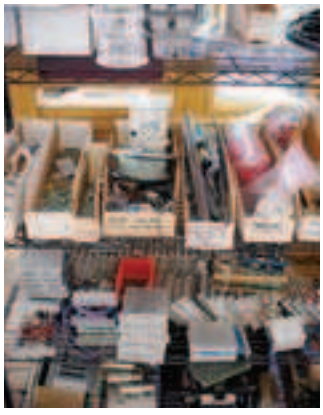
By KATHERINE BOURZAC *Photographs by* DANIEL HENNESSY


GT-46
GT-49
GT-50
WT-45

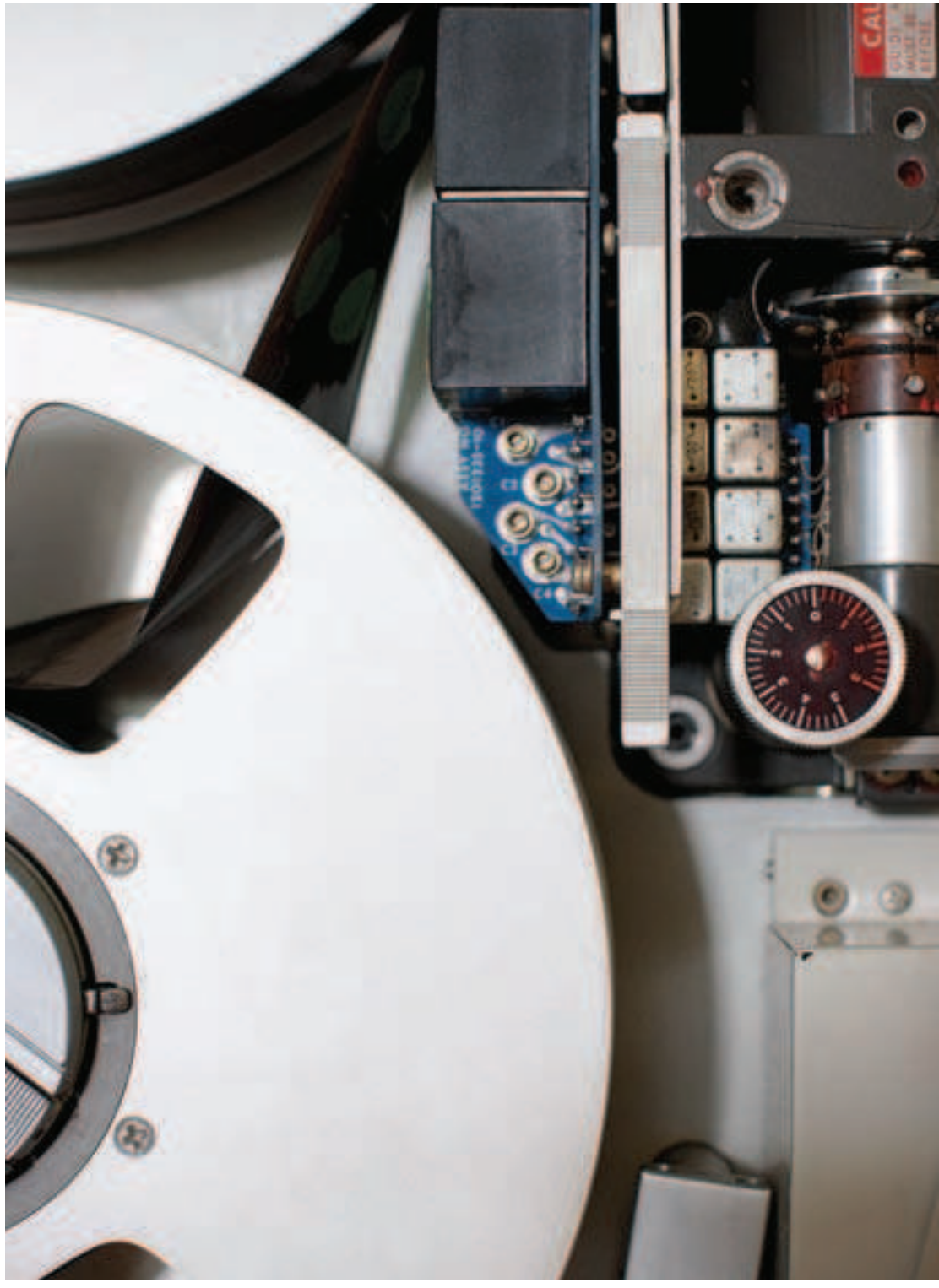
The images used to plan the Apollo landing sites were photographs of photographs: as the Lunar Orbiter data came in, NASA scientists displayed it on monitors and shot pictures of the images on the screen. But NASA did make backup recordings of the raw image transmissions. Each of the hundreds of tapes (above) contains the data for a single high-resolution photo. To recover them, the team first had to restore an old FR-900 tape drive (far right), beginning by washing it in the former restaurant's sink. It is connected to a custom-built demodulator to extract the image, an analog-to-digital converter, and a monitor for viewing the images. At right are reels used to verify the coördinates of moon images on tapes whose labeling system has been forgotten.

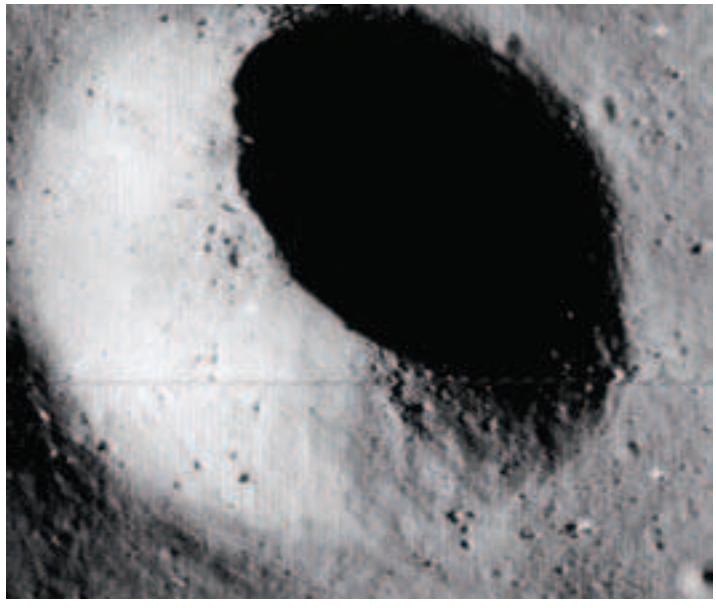

AMPEX





The back of the FR-900 has been signed by the people who brought the project to life, including Nancy Evans, a former NASA scientist who kept the tapes in her garage for 20 years. To restore the machine, they collected tools and extra parts scavenged from other tape readers (above). In order to read the tapes, the team also had to find one of the few remaining people who knew how to repair the tape drive's read heads, visible at right. The heads apply a magnetic field to the tape, inducing a change in electrical current. The data is then run through the demodulator to pull out the image signal, which in turn is run through an analog-to-digital converter.

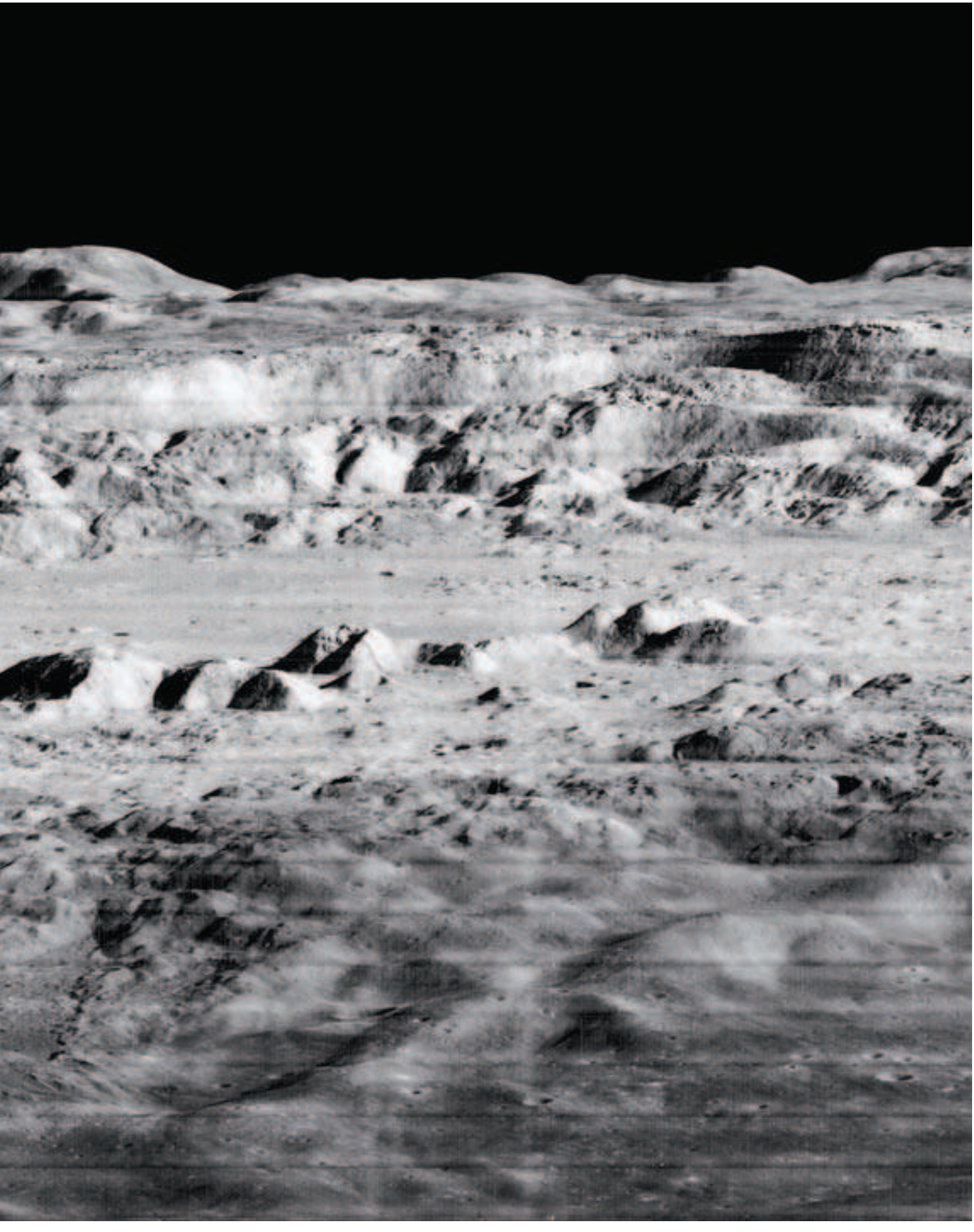




The recovered digital data is then processed on a computer. The orbiters sent out each image in multiple transmissions, each of which makes up a different strip of the whole. Using custom software and Photoshop, the researchers integrate the data strips into nearly seamless images at the full potential resolution. The best of these images show the lunar surface at a resolution of less than a meter. The group, led by Dennis Wingo, a space entrepreneur, has restored 12 images so far. The top image at left, which was taken in February 1967 by Lunar Orbiter 3, shows the landing site that was chosen for the failed Apollo 13 mission and subsequently explored by the Apollo 14 astronauts in 1971. Alan Shepard and Edgar Mitchell took photos of rock outcroppings at the rim of the dark crater at the bottom right of the frame; the newly restored image is so sharp that it can be blown up to reveal these very rocks (bottom left). At right is a restored image of the interior of the Copernicus crater that Lunar Orbiter 2 took by chance, in November 1966, as it was advancing the roll of film before shooting potential landing sites. Scientists at NASA and elsewhere have become more interested in the site since then: it's thought there might be water there. Now that they're restored, these remarkably detailed images of the lunar surface will be used to plan future NASA missions to the moon.

For more moon images, take a snapshot of this code with your smart phone (for instructions, see p. 25) or visit **technologyreview.com/moon**

LOIRP/NASA



EmTech@MIT 2009 Breakout Panel Preview

In September, at **EmTech@MIT 2009**, the world's most talented and influential leaders in technology will immerse themselves in the most pressing problems—and greatest opportunities—facing technology today. Over the course of the conference, new connections, new insights, and new friendships will mark the beginning of bold new endeavors. EmTech@MIT brings the ideas of emerging technology to life—and does so through the exploration of the hottest topics in tech today.

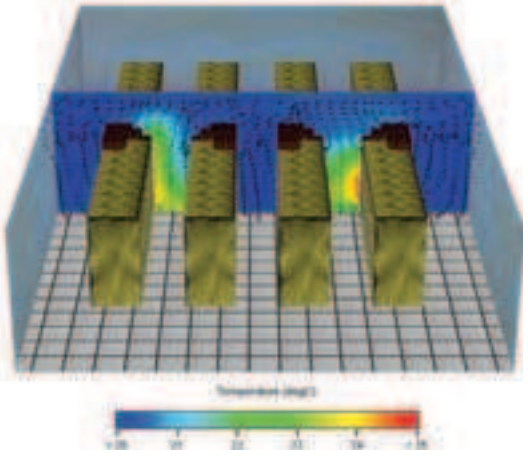
"Greening IT"

Imagine a mid-sized country populated entirely by computer servers. Ridiculous? Not a bit. Datacenters worldwide already consume as much energy as the whole of the Netherlands. What's more, these machines are multiplying at a staggering rate. The energy consumed by datacenters in the U.S. accounts for 1.5% of national consumption. If left unchecked, the figure will quadruple by 2020, according to a study released by McKinsey and the Uptime Institute in 2008.

Most datacenters are terribly wasteful, too. An analysis by the Department of Energy from April 2009 concludes that facilities, on average, convert only 15% of the energy they consume into useful computing and could be made up to 50% more efficient.

Datacenter energy use is a big problem. It's also a big opportunity.

A panel of business, academic, and government experts will help unravel the challenges and explore the most promising solutions to improving datacenter efficiency at a panel entitled "Greening IT."



Air conditioning units between rows of equipment help improve cooling efficiency in this simulation.

IMAGE: MENTOR GRAPHICS

As companies wake up to the need for datacenter efficiency, they are faced with a bewildering array of problems. For one thing, most datacenters have way more capacity than they actually need, because the temptation is always to overprovision in case of failure. This means that up to 30% of datacenters are functionally "dead" at any one time, according to the McKinsey-Uptime report.

The Green Grid, a consortium established in 2007 to promote IT efficiency across the industry, suggests that many companies need to completely rethink capacity, powering down unused equipment and switching to less power-hungry components to save on energy. Wasteful power supply is another common predicament, and cooling, which can account as much as half of all energy use, is perhaps the biggest conundrum of all.

If identifying the most significant problems is tricky, identifying the best, most cost-effective solutions is trickier still. Different kinds of power supply can reduce inefficiencies, but software can also track energy consumption and manage hardware more efficiently. Virtualization software can get more out of servers, but companies that once built or leased their own server farms now have the option to use cloud computing services instead. Cooling can be localized or facilities can be redesigned to make better use of existing technologies. More radical schemes include chilling machines inside giant cooling towers or simply moving data to colder locations when the weather gets too hot.

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35 INNOVATORS UNDER 35

CREATING OUR ANNUAL LIST OF YOUNG INNOVATORS, which recognizes 35 exceptional leaders in technology who are under the age of 35, is an exhaustive—and exhausting—process. We start by scouring the world to find outstanding candidates and recruiting a panel of expert judges; we end with a concerted effort to create profiles that precisely and clearly explain the winners' accomplishments and why they matter. But every year, there is a moment for each of us, as we talk to these amazing technological trendsetters and hear about their work firsthand, when the excitement that TR35 members feel about their work becomes contagious.

Though they work in disparate fields and places—from clean rooms and labs to factories and slums, from New England to Nicaragua—this year's winners are united in their urgent desire to improve what we do and get it done sooner, to help us accomplish more and live better. They're building safer, simpler, speedier electronics and software; better, more resilient medical tests and treatments; cheaper, cleaner energy sources. The 2009 TR35 are out to change our world. We hope you enjoy learning about them as much as we did. *—The Editors*

INNOVATOR OF THE YEAR

Kevin Fu, 33

UNIVERSITY OF MASSACHUSETTS, AMHERST

Defeating would-be hackers of radio frequency chips in objects from credit cards to pacemakers

Could implanted medical devices that use wireless communication, such as pacemakers, be maliciously hacked to threaten patients' lives? Kevin Fu is no stranger to such overblown scenarios based on his research, though he prefers to stick to talking about technical details. But Fu, a software engineer and assistant professor of computer science, is a security guy. And security people think differently.

"Anyone who works in the world of security—they always have an adversary in mind," Fu explains, sitting behind his desk on the second floor of the UMass Amherst computer science building. "That's how you can best design your systems to defend against it."

The threats Fu researches are chiefly those connected to the security of radio frequency identification, or RFID. RFID is an increasingly common technology, used in everything from tags for shipping containers to electronic key cards, from ExxonMobil's Speedpass key-chain wands to Chase's no-swipe "Blink" credit cards. It allows billing and personal information to be shared quickly and wirelessly. But not, Fu realized back in 2006, very securely.

After testing more than 20 such "smart" or no-swipe credit cards from MasterCard, Visa, and American Express, Fu and his colleagues found that they could lift account numbers and expiration dates from several of the cards—even cards inside a wallet—just by walking past them with a homemade scanner.

Criminals troll mailboxes, shopping malls, and airports, harvesting nearby RFID information for use in identity-theft scams. Basically, they pick your pocket without ever touching your pocket. Making these cards truly secure would require good encryption software—Fu's specialty. But encryption requires a steady supply of energy, something that the passive, externally powered RFID chips used in these applications don't have. "The inspiration was about the programming," Fu explains. "But the programming won't work without an RFID computer to program. And the RFID computer won't work without solving the energy issues." He breaks a weary smile. "So, thus far, it's been something like a two-year sideline."

The only way for Fu to resolve this catch-22 is to invent new technology—a project he's working on with a team led by Wayne Burleson, a professor of electrical and computer engineering. But even as he wrestled with this problem, Fu found himself wondering, as only a security guy can: if financial information is vulnerable, what about seemingly more obscure targets with far bigger consequences?

This is what first brought him to the heart-attack machine.

At his desk, Fu clicks through a PowerPoint slide show of bad-guy examples, from the madman who put cyanide-laced Tylenol on Chicago drugstore shelves in 1982 to the hacker who posted seizure-inducing animations on an Internet message board for epileptics.

"It might seem paranoid," Fu admits, "but from a security standpoint, you need to start with the fact that bad people do exist." And there seemed no better place to hunt such misanthropes than the world of medicine.

Fu began wondering about the security of medical devices that use RF communication, such as pacemakers and defibrillators. He discussed the problem with his longtime colleague Tadayoshi Kohno, assistant professor of computer science and engineering at the University of Washington and a veteran investigator into the vulnerabilities of computer networks and voting machines (*see TR35, September/October 2007*).

"Kevin is a fantastic researcher," Kohno says. "His research is now covered in almost every undergraduate computer-security course that I know of. And his insights are exceptionally deep." Together, Fu and Kohno took their questions about defibrillators far from the computer science lab—into the world of cardiologist William H. Maisel, director of the Medical Device Safety Institute at Boston's Beth Israel Deaconess Medical Center.

The two explained to Maisel's wide-eyed staff how security people think. In turn, the medical professionals introduced the security researchers to Cardiology 101—starting with pacemakers and defibrillators, devices that are implanted in some half-million people around the world every year. Basically, a pacemaker regulates aberrant heartbeats with gentle metronomic

Photographs by STEVE MOORS

STEPPING BACK
Kevin Fu takes the point of view of a malevolent hacker to uncover dangerous security flaws in wireless devices.

Photograph by GREGG SEGAL

2009 TR35 JUDGES

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Partner, Flagship Ventures

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Aimée Rose*
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Micah Siegel*
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Chris R. Somerville
Philomathia Professor of Alternative Energy, and director, Energy Biosciences Institute, University of California, Berkeley

JB Straubel*
Chief technical officer, Tesla Motors

Heather (Haitao) Zheng*
Associate professor of computer science, University of California, Santa Barbara

Daphne Zohar*
Founder and managing partner, PureTech Ventures

**Past TR100/TR35 honoree*

pulses of electricity, while a defibrillator provides a big shock to "reboot" a failing heart. Merged, they form an implantable cardioverter defibrillator, or ICD. The ICD is designed to stop a heart attack in a cardiac patient. But, Fu and Kohno wondered, could it create one instead?

In his UMass office, Fu pulls out a shoebox containing the works of an ICD. It looks the way the Tin Man's heart might: padlock-sized and encased in hard, silvery surgical steel, now peeled away can opener–style. I instinctively reach in, drawn like a magpie to the shiny objects. Fu quickly jerks the box away. "Um, you don't want to touch that," he says. "The coil in these things delivers 700 volts"—enough juice to stop your heart.

He points out the matchbook-sized microchip and antenna coil—technology that connects the latest-generation ICDs with the Internet, allowing doctors to reprogram a device without surgery. From the perspective of cardiologists and patients, this wireless programming is a godsend. But from Fu's viewpoint, it represents a new security risk. And so he wondered: Could black-hat hackers listen in on the wireless communication between an ICD and its programming computer? Could they make sense of what they heard and use it to inflict harm?

"Most people who make these devices don't think like this," Fu says. "But this is how the adversary thinks. He doesn't play your game; he makes his own game." To assess the security threat, the researchers needed to play the hacker's game.

Fu's team set out to create a technique to eavesdrop on defibrillator chatter. The hardware was just off-the-shelf stuff—a platform designed to allow researchers and serious hobbyists to build their own software radios. It has been made into FM radios, GPS receivers, digital television decoders—and RFID readers. All that was left was to write the software, rip the antenna coil out of an old pacemaker, solder it into the radio—and voilà, they had a transmitter.

"It worked pretty well—amazingly well," Fu says. After "nine months of blood and sweat," they could intercept digital bits from an ICD—but they had no idea what those bits meant. His students trudged back to the lab to figure out how to interpret them. Using differentiation analysis—basically, changing one letter of a patient's name and then listening to how the corresponding radio transmission changed—they were able to painstakingly build up a code book.

Now their homemade software radio could listen in on and record ICD programming commands. The device could also rebroadcast those recordings, as fresh commands, to any nearby ICD. It had become dangerously capable of playing doctor.

Fu discovered one set of commands that would keep an ICD in a constant "awake" state, surreptitiously draining the battery to devastating effect. "We did a back-of-the-envelope calculation on this," he explains. "A battery designed to last a couple years

CATCHING BUGS By exposing ways for wireless devices to be hacked, Fu has alerted manufacturers to the potential dangers that their customers face. He found that implanted cardiac devices are particularly vulnerable.

could be drained in a couple weeks. That alone was a notable risk."

Even more notable, Fu's software radio was capable of completely reprogramming a patient's ICD while it was in his or her body. The researchers were able to instruct the device not to respond to a cardiac event, such as an abnormal heart rhythm or a heart attack. They also found a way to instruct the defibrillator to initiate its test sequence—effectively delivering 700 volts to the heart—whenever they wanted.

Fu doesn't like to think of himself as having built a heart-attack machine, or even of discovering that such a thing could be built. Though he is an academic who doesn't shy away from pursuing real-world applications for his theoretical technologies, that "real world" is usually at least 10 years in the future. But the ramifications of the ICD-programming radio were both immediate and chilling: the device could be easily miniaturized to the size of an iPhone and carried through a crowded mall or subway, sending its heart-attack command to random victims.

A heart-attack machine? Really? It would be foolish, Fu says, not to recognize that there are depraved people out there, more than capable of building and using such a machine to inflict harm on random innocents "just for kicks." To this extent, the issue of protecting remote programming access to ICDs is directly related to the issue of protecting RFIDs. Encrypting the communication is the only way to shield millions of people from random risks. It doesn't take a Fu to come up with practical solutions, but by exposing the security dangers he has provided a valuable, perhaps even life-saving, alert to manufacturers.

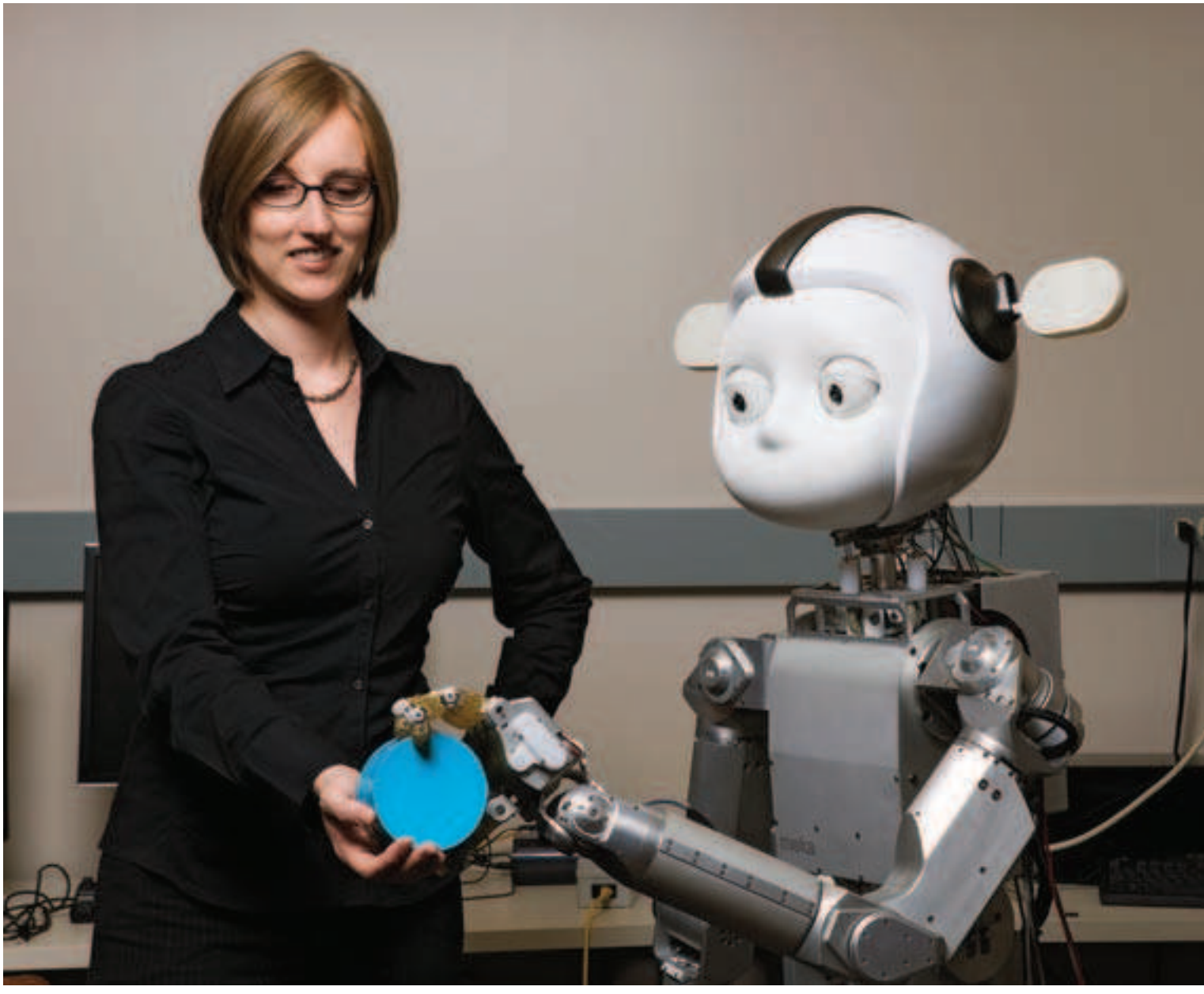
Fu is too smart to engage in speculation about how the technology could be abused, except to say that he'd be very surprised if there weren't "people already working on this." In the best case, we'll never know how foresighted he was; medical-device makers will eliminate the threat before hackers ever exploit it. "Kevin is a computer scientist who also has the ability to look at problems like a medical doctor and like a patient," says Maisel. "The work Kevin is doing now—relating to medical-device security and privacy—has the potential to impact millions of people."

How about the more dramatic scenarios? Imagine a spy agency using printed circuitry to put a heart-attack machine into a newspaper, delivered with morning coffee to a foreign leader with a pacemaker. Or a Lex Luthor–like supervillain who retrofits a radio tower to broadcast his death ray to entire populations.

Kevin Fu—professor, researcher, scientist—rolls his eyes. "All I can say about that one," he says with a laugh, "is it might make a pretty good movie." —*Charles Graeber*

"Most people who make these devices don't think like this. But this is how the adversary thinks. He doesn't play your game; he makes his own game."

To see interviews with TR35 winners, take a snapshot of this code with your smart phone (for instructions, see p. 25) or visit **www.technologyreview.com/tr35.**



HARDWARE

Andrea Thomaz, 33

GEORGIA INSTITUTE OF TECHNOLOGY

Robots that learn new skills the way people do

BEFORE ROBOTS can be truly useful in homes, schools, and hospitals, they must become capable of learning new skills. Andrea Thomaz, an assistant professor of interactive computing, wants them to learn from their users, so that experts don't have to program every task. She aims to make robots that not only understand a human teacher's verbal instructions and social signals but give social feedback of their own, using gestures, expressions, and other cues to let the person know whether they have correctly understood the directions.

Thomaz has designed machine learning algorithms based on human learning mechanisms and built them into her robots Junior and Simon, which have faces that make basic expressions and hands that can grasp simple objects. In experiments with people untrained in formal teaching, Junior has quickly learned enough about things in its environment to catch on to tasks such as opening and closing a box.

—Kristina Grifantini

SIMON DOES The robot Simon uses social cues to communicate whether it has understood what an instructor intended. Andrea Thomaz hopes that these abilities, in combination with computer vision, speech processing, and grasping capability, will enable Simon to operate successfully in the real world.

YVONNE BOYD

NANOTECHNOLOGY

ANDREW HOUCK, 30

PRINCETON UNIVERSITY

Preserving information for practical quantum computing

AMONG THE most promising approaches to building a quantum computer is using superconducting circuits as quantum bits, or qubits. But controlling the qubit without destroying the information tucked inside it is a major challenge.

Andrew Houck, an assistant professor of electrical engineering, developed a superconducting qubit called a transmon that helps keep quantum information intact.

The data in a qubit—*0*, *1*, or a quantum superposition of the two—is represented using different energy and phase states in the circuit, but stray electrical fields can easily destroy these states during readout. Instead of targeting the source of interference, as other researchers have, Houck armored the qubit, adding a capacitor that makes it difficult for stray electrons to interfere.

Getting data from the transmon is the next hurdle. Usually the qubit is read directly, by measuring changes in charge, but that's not possible with the transmon. So Houck coupled it to a microwave photon, which interacts differently with the qubit depending on its state. By measuring the photon, it's possible to infer the qubit's state and thus extract its information.

While the quantum data in transmons lasts a few microseconds—an order of magnitude longer than in previous qubits—there's still a way to go before millions of qubits can be used to make a large-scale quantum computer. *—Anne-Marie Corley*

PADDY MILLS (HOUCK); BRYAN CHRISTIE DESIGN (THAXTON)

BIOTECHNOLOGY

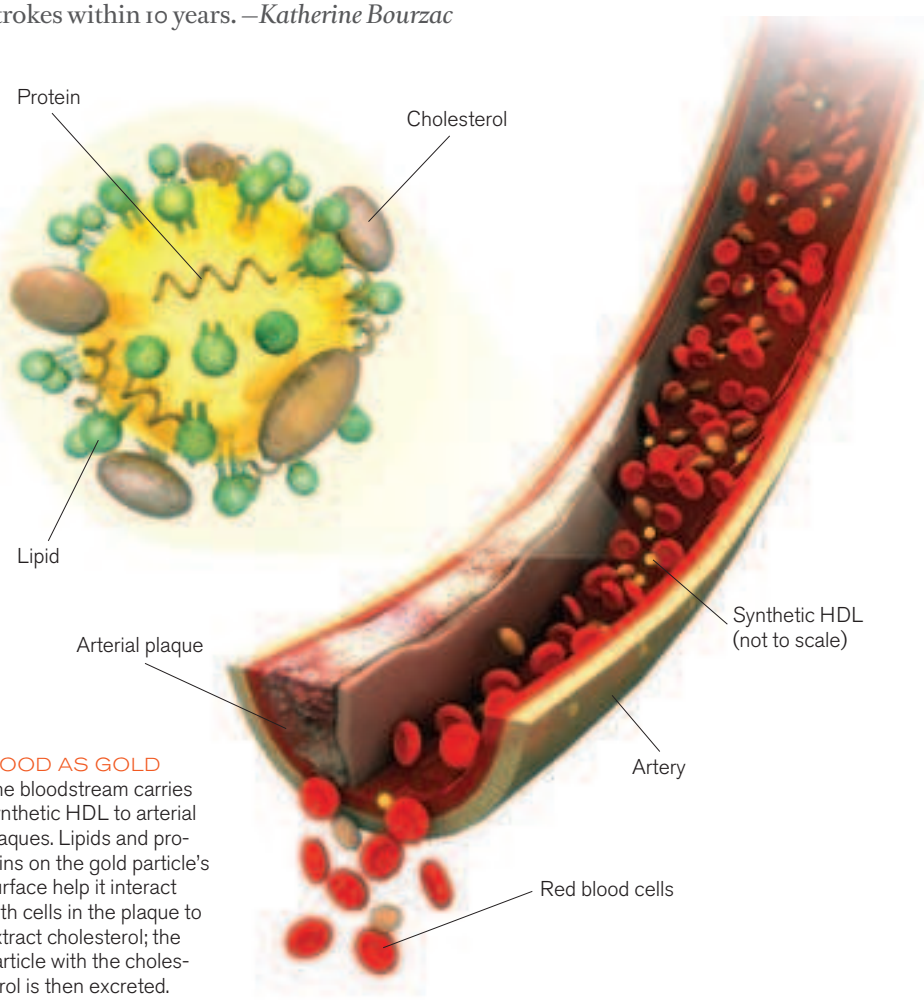
C. Shad Thaxton, 33

NORTHWESTERN UNIVERSITY

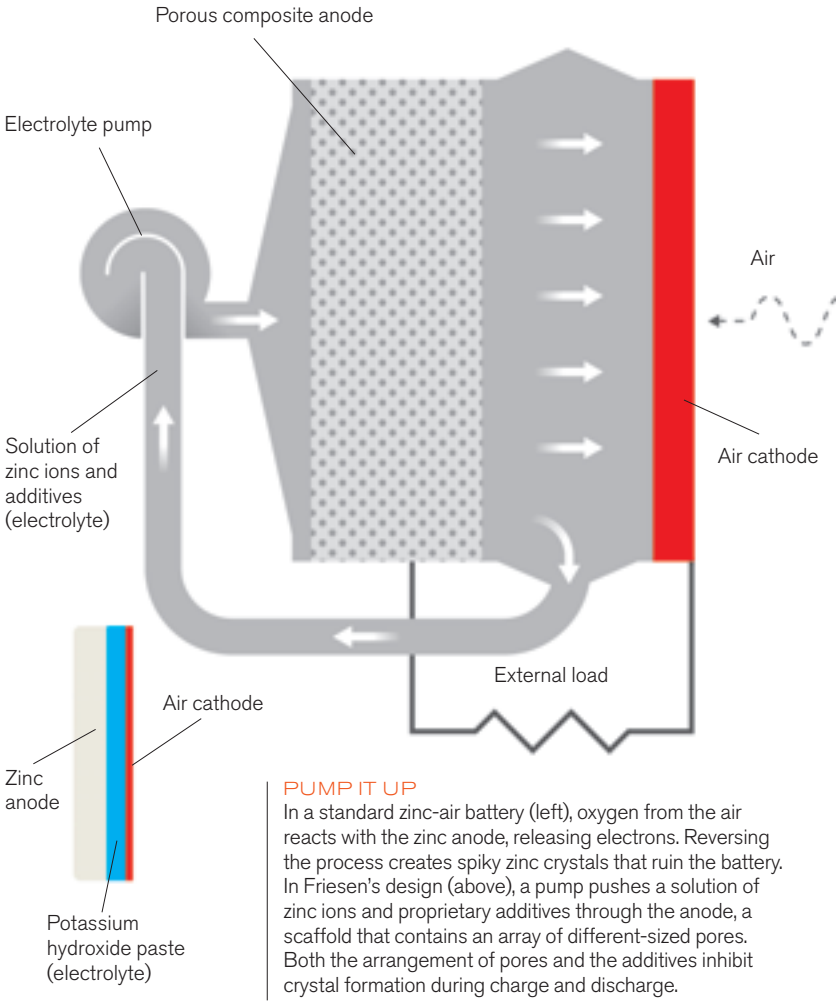
Nanoparticles could treat cardiovascular disease by mimicking "good cholesterol"

TO COMBAT cardiovascular disease, Shad Thaxton, an assistant professor of urology, designed a nanoparticle that may be able to carry cholesterol right out of the body.

Several drugs treat cardiovascular disease by lowering levels of the lipoprotein complex LDL, commonly called "bad cholesterol" because it deposits the cholesterol in blood-vessel walls. But no existing therapies can directly increase HDL, or "good cholesterol," which carries the sticky molecule through the bloodstream and to the liver for excretion. Thaxton's nanoparticles mimic HDL. At their heart are gold spheres five nanometers in diameter; these are coated with fat and protein molecules that enable them to bind tightly to cholesterol. The work is in its early stages, but Thaxton envisions synthetic-HDL nanoparticles that will transport cholesterol from blood-vessel plaques to the liver to prevent and treat cardiovascular disease. If proved safe and effective, he says, synthetic HDL could be used to prevent heart attacks and strokes within 10 years. *—Katherine Bourzac*



GOOD AS GOLD
The bloodstream carries synthetic HDL to arterial plaques. Lipids and proteins on the gold particle's surface help it interact with cells in the plaque to extract cholesterol; the particle with the cholesterol is then excreted.



PUMP IT UP

In a standard zinc-air battery (left), oxygen from the air reacts with the zinc anode, releasing electrons. Reversing the process creates spiky zinc crystals that ruin the battery. In Friesen's design (above), a pump pushes a solution of zinc ions and proprietary additives through the anode, a scaffold that contains an array of different-sized pores. Both the arrangement of pores and the additives inhibit crystal formation during charge and discharge.

ENERGY

Cody Friesen, 31

FLUIDIC ENERGY

Making cheaper, higher-energy batteries to store renewable energy

ZINC-AIR batteries, which use zinc metal as the anode and an alkaline paste as the electrolyte, are simple, inexpensive, nontoxic, and long-lasting. But engineers haven't been able to figure out how to recharge them. Cody Friesen, an associate professor of materials science at Arizona State University, solved the problem by using a porous electrode and a liquid solution of zinc ions and additives as the electrolyte. He cofounded Fluidic Energy in 2007 to commercialize the design, and outside testing of its commercial prototype is planned for late fall. Within two years, Friesen hopes to be selling batteries that can hold twice as much energy as the lithium-ion batteries used in laptops and, increasingly, in electric cars. He calculates that his rechargeable metal-air batteries could ultimately hold 10 times as much energy as lithium-ion devices at a much lower cost. The first market he's aiming for is storage of wind- and solar-generated electricity, but the batteries could also be useful in hybrid electric vehicles and portable electronics. *—Neil Savage*

INTERNET

Jaime Teevan, 32

MICROSOFT RESEARCH

Using personal information to improve search results

IN 1997, when search engines were relatively new, Jaime Teevan took an internship at Infoseek the summer before her senior year at Yale. William Chang, the chief technology officer, put her in a room with some research and told her to "find something fun to do." She came up with some ideas for judging link quality and helping people navigate the company's search engine, and she wrote the code to implement the changes. "Once, I brought the search engine down for a couple of hours," she says with a laugh.

But she also discovered a career path. Today, the Microsoft researcher is a leader in using data about people's knowledge, preferences, and habits to help them manage information. She studies the ways people navigate the flood of information available in the digital age and builds tools to help them handle it.

By now, personal information management has become an Internet buzzword. But Teevan pioneered the field as a graduate student working with David Karger, a professor in MIT's Computer Science and Artificial Intelligence Laboratory. "She literally almost single-handedly created this whole area," says Eric Horvitz, a principal researcher who manages the study of search and retrieval at Microsoft Research.

She began by studying how people search the Internet. They use such different strategies, she found, that a one-size-fits-all search engine can never satisfy everyone. So Teevan started building tools that sort Internet search results according to a user's personal data, previous searches, and browsing history.

One of her first tools was a search engine called Re:Search. Early on, Teevan discovered that people are often looking for information they've already found before; more than half of all Web-page visits and a third of all search queries are repeats. But since the Web

ARTHUR MOUNT

is always changing, people often have a hard time finding a site again. Re:Search relies on information from a user's past searches to determine which items are more relevant to him or her. Teevan found that people tend to remember the first item in a list of previous search results, as well as items they clicked on; they also tend to get confused if the results they clicked on have changed position in the list. So she designed Re:Search to keep clicked links in their previous positions and insert new links in positions where they will be noticed without being confusing or distracting.

One of Teevan's key ideas is that search engines can employ information about users to help them zero in on the results they need. Since she joined Microsoft Research in 2006, she's developed a number of experimental browser plug-ins that work with Internet Explorer and that will refine search results for each user. One, called PSearch, uses an index of documents, e-mails, and other material on the user's hard drive to customize the results delivered by an Internet search engine. For instance, if she types her husband's last name into a typical search engine, the top hits are for a financial-services firm that shares his name. When she turns PSearch on, the first sites listed relate to her husband.

Horvitz says that almost every computer at Microsoft has PSearch installed and that it saves employees immense amounts of time. "What I like best is that all the personalization is going on on your desktop," he says. In fact, PSearch never shares a user's personal information with the search engine—the results are re-sorted after they're delivered to the user's computer.

Teevan's programs have yet to be released commercially, and because search is such a competitive area for Microsoft, both she and Horvitz declined to discuss any such plans. But both eagerly talk about her contributions to Microsoft's new search engine, Bing. Teevan says she met regularly with Bing's developers to help them understand how people search and how that knowledge might be used to improve search results. Horvitz points more directly to the left-hand column of the Bing search results page, where a short list titled "Search History" appears. "The work Jaime is doing—some of it involves memory between sessions, to make your search more effective," he says. "You see just the tip of the iceberg right now in the current Bing search." Teevan's work is actually far more advanced, Horvitz says. Hinting at things to come, he adds, "You might watch that corner of Bing over time." —*Kurt Kleiner*

MARC ROSENTHAL (TEEVAN); PADDY MILLS (DASH)

NANOTECHNOLOGY

RANJAN DASH, 32

Y-CARBON

Nanoporous carbon could help power hybrid cars

PROBLEM: Ultracapacitors, which last longer than conventional batteries and can deliver stronger bursts of power, hold great promise as energy-storage devices for applications such as hybrid electric vehicles. But ultracapacitors typically can't store as much energy as batteries, so they need to be recharged frequently. That drawback has limited their use.

SOLUTION: As a graduate student in materials science at Drexel University, Ranjan Dash used a novel chemical recipe to engineer nanoscopic pores into the carbon materials used in ultracapacitors. The tiny pores, whose size can be tuned with subnanometer precision, provide more surface area for charged particles to stick to, doubling the amount of energy the ultracapacitors can hold. Dash cofounded Y-Carbon, a startup based in King of Prussia, PA, to commercialize the technique, and he now serves as its chief technology officer. He says that his company has already developed a prototype ultracapacitor. The plan is to partner with other companies to develop this and other applications for the porous material, which Y-Carbon will manufacture. The first ultracapacitor products could be on sale in about two and a half years, Dash says.
—*Neil Savage*

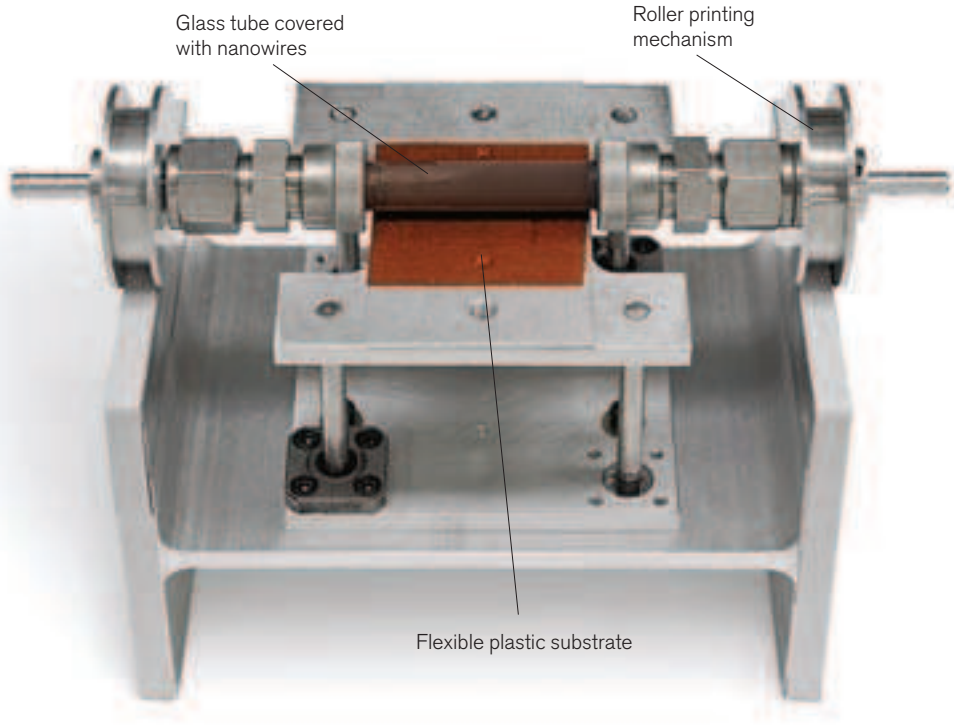
NANOTECHNOLOGY

VERA SAZONOVA, 30

NAT'L RESEARCH COUNCIL CANADA

World's smallest resonator could lead to tiny mechanical devices

MICROELECTROMECHANICAL systems, or MEMS, play a key role in gyroscopes, tiny chemical sensors, optical switches used in the telecom industry, and more. An even smaller version of the technology—nanoelectromechanical systems, or NEMS—could likewise have broad technological importance. Vera Sazonova has made the world's smallest NEMS device: a tiny resonator that consists of a single carbon nanotube suspended over a silicon gate. A voltage at the gate makes the nanotube vibrate, creating a high-frequency current. Since the current is hard to detect, Sazonova applied another voltage at a slightly different frequency; the two signals mix to create a third, low-frequency current that is easier to pick up. Potential applications include ultrasensitive motion detectors, sensors that can detect the mass of molecules, and even devices for detecting gravitational waves. *—Prachi Patel*



NANOTECHNOLOGY

Ali Javey, 29

UNIVERSITY OF CALIFORNIA, BERKELEY

"Painting" nanowires into electronic circuits

NANOWIRES COULD be the basis of tomorrow's advanced electronics, from cheap solar cells to high-resolution displays. But it's been difficult to arrange the tiny strands precisely. Ali Javey, an assistant professor of electrical engineering and computer science, has become a master at doing so. His latest tool for making high-quality circuits: a roller printer. He coats a glass cylinder with a catalyst and puts it in a chemical-vapor deposition chamber, where its surface sprouts nanowires. When the cylinder is pressed against a flexible piece of plastic or a silicon wafer, the tips of the nanowires cling to the flat surface; as the tube rolls, the wires are dragged and combed into straight rows before detaching from the roller. So far, Javey has used the technique to print transistors based on germanium, silicon, and indium arsenide nanowires. He has also printed arrays of light-sensing cadmium selenide nanowires, which can be used as photosensors for imaging applications. *–Katherine Bourzac*

ENERGY

ANDREW PERLMAN, 34

GREATPOINT ENERGY

Slashing carbon emissions by converting coal into natural gas

ONE OF THE biggest challenges in fighting global warming is reducing carbon dioxide emissions from the burning of coal, a cheap and abundant but dirty fuel. In 2004, serial entrepreneur Andrew Perlman founded GreatPoint Energy to commercialize a process for converting coal into methane (the main component of natural gas), which emits half as much carbon dioxide when burned to generate a given amount of electricity. The carbon dioxide that's produced in the conversion process is easy to capture for storage underground. GreatPoint, where Perlman is president and CEO, has built a

demonstration plant in Somerset, MA, and plans to build its first commercial plant as soon as next year. Meanwhile, Perlman has cofounded additional ventures that are developing, among other things, cheaper desalination plants, anti-obesity medicines, drugs that fight diseases of old age, and processes for converting garbage into biofuels and generating electricity by extracting heat from rocks located miles underground. *–Kevin Bullis*

PADDY MILLS (SAZONOVA); ERIK PAWASSAR (JAVEY); CONRAD WARRE (PERLMAN)

BIOTECHNOLOGY

EREZ LIEBERMAN-AIDEN, 29

HARVARD UNIVERSITY/MIT

Quantitative tools offer new insights into evolution

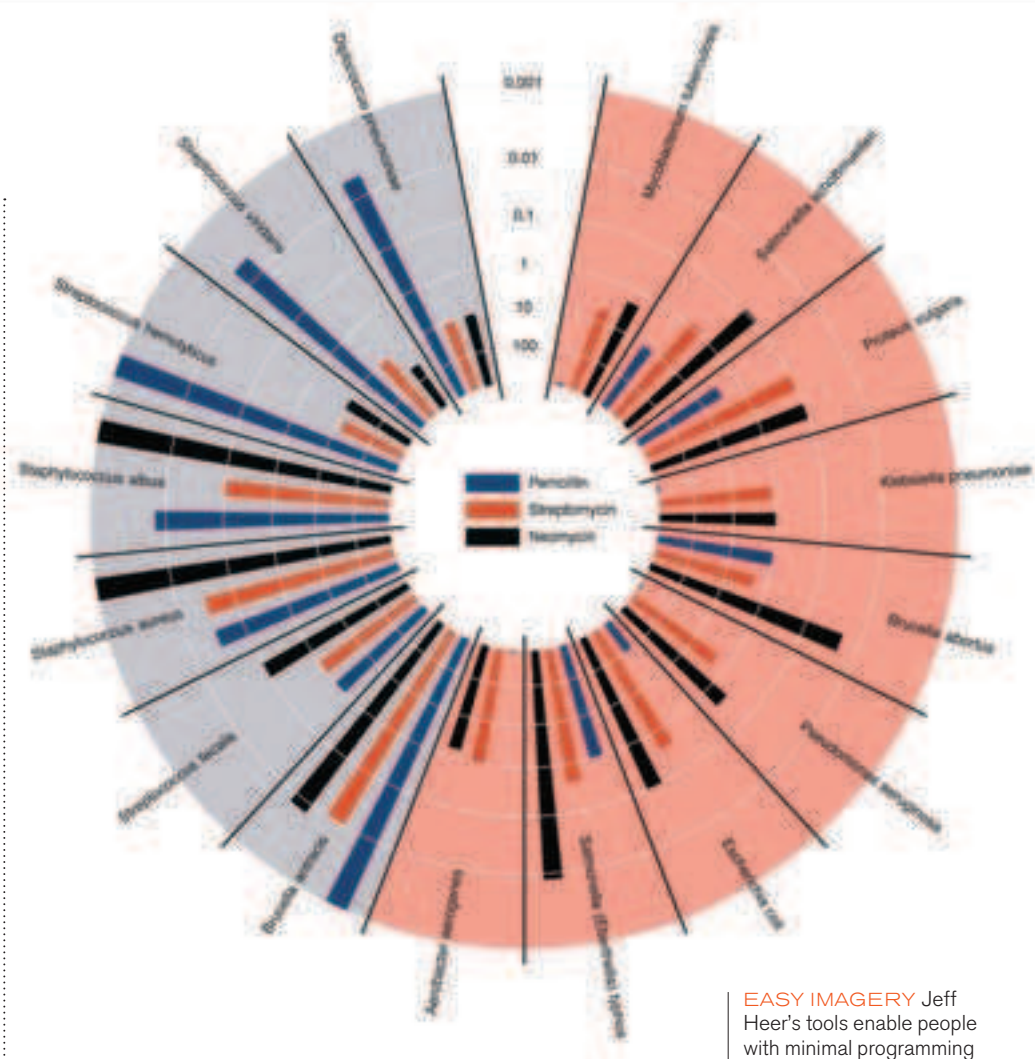
WHEN EREZ Lieberman-Aiden started his PhD in applied math in 2003, evolutionary theory couldn't handle the complex shapes of real-world populations. So he helped it adapt by combining it with specialized mathematical tools. His advances have allowed evolutionary biologists to include more variables in their models.

His next challenge: "People talk about the evolution of culture and language, but I found myself wondering whether evolution is really relevant to culture," Lieberman-Aiden says. Working with Google, he and colleagues are building tools that can scan massive collections of digital texts and quantify how often a word—say, *communism*—appears in those from a particular era and place. This makes it easy to observe the movement of ideas, culture, and language across time and space.

Recently, Lieberman-Aiden has shifted his research toward genomics. Scientists can determine the sequence of bases in DNA, but they've had no way to know the genome's overall structure. Lieberman-Aiden has codeveloped a method that determines both sequence and structure—revealing, for instance, conformational changes that bring two genes close even though they're far apart along the length of a chromosome.

—Erika Jonietz

PADDY MILLS (LIEBERMAN-AIDEN); COURTESY OF JEFFREY HEER



EASY IMAGERY Jeff Heer's tools enable people with minimal programming experience to generate intricate and informative data visualizations, like this re-creation of a chart originally published in 1951 to show the effectiveness of three antibiotics.

INTERNET

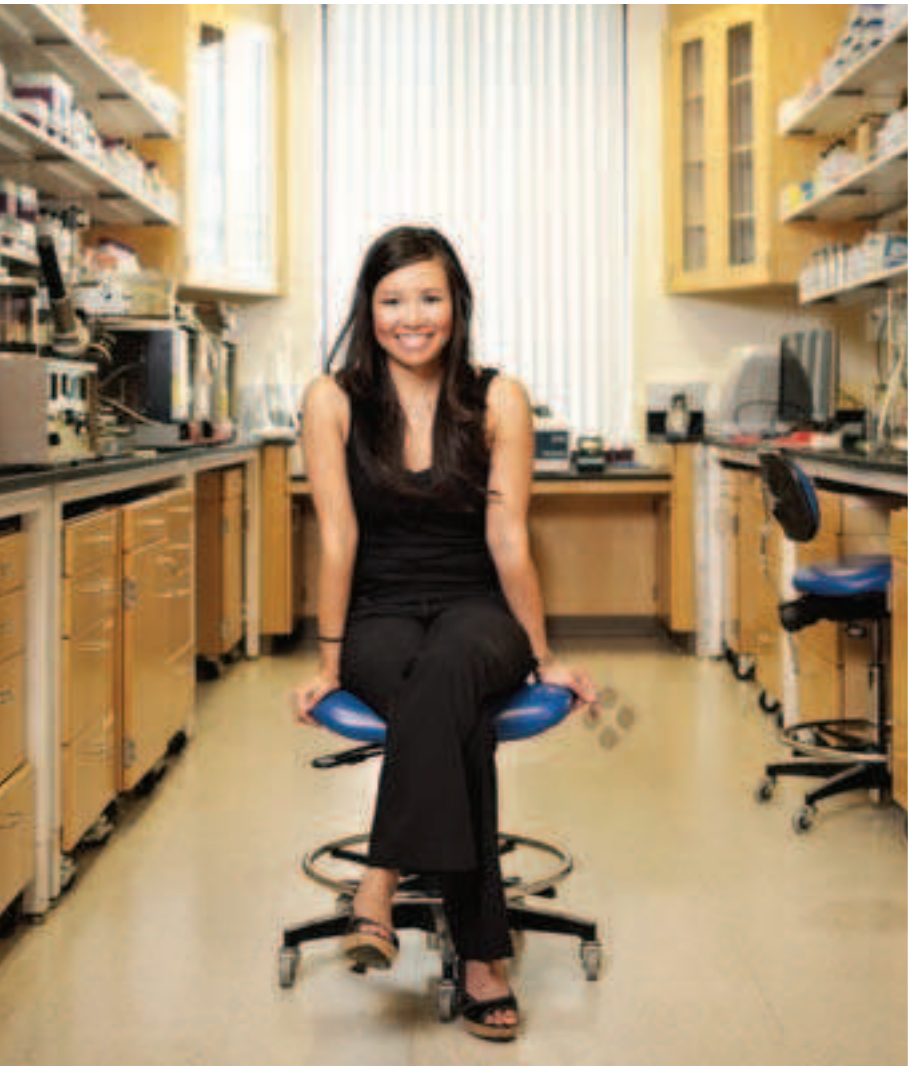
Jeffrey Heer, 30

STANFORD UNIVERSITY

Easy-to-use tools allow people to present data in creative and interesting ways

LISTS OF NUMBERS often don't mean as much as charts, graphs, and interactive graphics that can reveal unexpected trends. To help people make them, Jeff Heer, an assistant professor of computer science, led a project that created easy-to-use open-source visualization software called Protovis.

Programs like Microsoft's Excel make it simple to turn data into charts, but they provide few options. Powerful analytical programming languages can do more but are complicated to use. Protovis lets people who have only token programming skills concentrate on the design of a visualization rather than worrying about how to structure complex computer code. The software provides chunks of code that correspond to different aspects of visual information display, such as shapes and colors; users string these chunks together to create a complete graphic. People can also easily integrate the visualizations into Web pages to facilitate sharing and discussion. Protovis currently runs in Web browsers such as Firefox, Chrome, and Safari. Heer is working on tools that make it easier to create interactive and animated graphics. *—Kate Greene*



BIOTECHNOLOGY

Michelle Khine, 32

UNIVERSITY OF CALIFORNIA, IRVINE

A children's toy inspires a cheap, easy production method for high-tech diagnostic chips

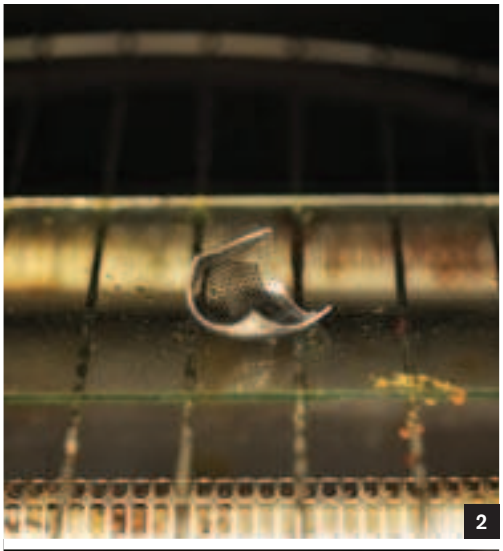
IN 2006, Michelle Khine arrived at the University of California's brand-new Merced campus eager to establish her first lab. She was experimenting with tiny liquid-filled channels in hopes of devising chip-based diagnostic tests, a discipline called microfluidics. The trouble was, the specialized equipment that she previously used to make microfluidic chips cost more than $100,000—money that wasn't immediately available. "I'm a very impatient person," says Khine, now an assistant professor at the University of California, Irvine. "I wanted to figure out how I could set things up really quickly."

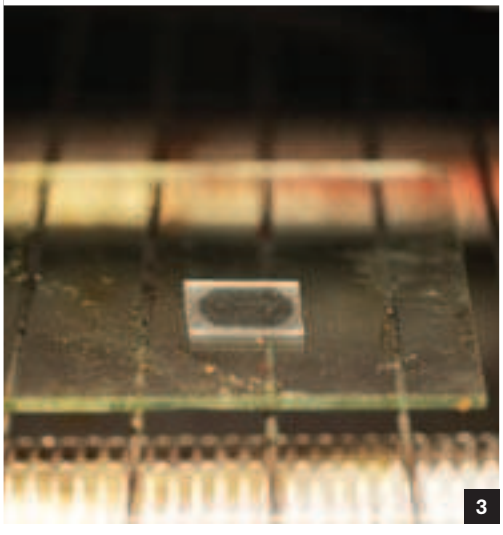
Racking her brain for a quick-and-dirty way to make microfluidic devices, Khine remembered her favorite childhood toy: Shrinky Dinks, large sheets of thin plastic that can be colored with paint or ink and then shrunk in a hot oven. "I thought if I could print out the [designs] at a certain resolution and then make them shrink, I could make channels the right size for microfluidics," she says.

To test her idea, she whipped up a channel design in AutoCAD, printed it out on Shrinky Dink material using a laser printer, and stuck the result in a toaster oven. As the plastic shrank, the ink particles on its surface clumped together, forming tiny ridges. That was exactly the effect Khine wanted. When she poured a flexible polymer known as PDMS onto the surface of the cooled Shrinky Dink, the ink ridges created tiny channels in the surface of the polymer as it hardened. She pulled the PDMS away from the Shrinky Dink mold, and voilà: a finished microfluidic device that cost less than a fast-food meal.

Khine began using the chips in her experiments, but she didn't view her toaster-oven hack as a breakthrough right away. "I thought it would be something to hold me over until we got the proper equipment in place," she says. But when she published a short paper about her technique, she was floored by the response she got from scientists all over the world. "I had no idea people were going to be so interested," Khine says.

Photographs by DAVE LAURIDSEN

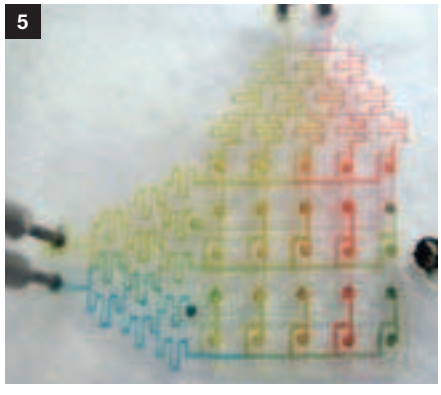




PURPOSEFUL PLAY Biomedical engineer Michelle Khine sits in her lab at the University of California, Irvine (far left), where she uses Shrinky Dinks straight from the toy store to build microfluidic devices.
1. Khine holds up a Shrinky Dink sheet on which she has printed several designs. She uses an ordinary laser printer to reproduce the patterns.
2., 3. Placed inside a toaster oven, a square of Shrinky Dink material shrivels as it heats up. The ink particles clump, creating ridges on the plastic. The miniaturized square will act as a mold for microfluidic chips made of polymer.
4. Khine peels a polymer microfluidic device from its Shrinky Dink mold.
5. Khine can also fabricate 3-D chips by melting etched Shrinky Dinks together.

At the same time, she faced considerable skepticism. How on earth, critics wondered, could you use a toy to make a sophisticated device that's normally forged from high-grade silicon? "People either love it or they laugh at me," Khine says. She hastens to point out that Shrinky Dink microfluidics isn't perfect—minute ink splatters from the printer, for instance, can give rise to slight irregularities in the finished channels.

Still, glitches like these don't pose a problem for most applications. And Khine has already found a way around a more serious difficulty: PDMS can absorb proteins, throwing off the results of sensitive tests. She has begun to make chips directly out of the Shrinky Dinks by etching the design into the plastic using syringe tips. As the plastic shrinks, the channels become narrower and deeper—perfect for microfluidics. She can even make three-dimensional chips by melting several etched Shrinky Dinks together. The whole process, from design to finished chip, takes only minutes.



Khine plans to use her chips to detect various medical conditions, and she hopes the cheap and portable devices will someday be used to diagnose HIV and other infections at the bedside. She has also found that by growing stem cells in a Shrinky Dink device that contains wells instead of channels, she can coax them to become heart muscle cells. Such a tool might allow researchers trying to grow those cells for tissue transplants to control the process more closely.

Douglas Crawford, associate executive director of the California Institute for Quantitative Biosciences, sees advantages in Khine's approach. "Michelle's technique is better, faster, and cheaper—it can put microfluidic prototyping into the hands of every lab," he says.

Khine recently printed metal patterns on Shrinky Dinks. As the plastic shrinks, the metal buckles to form shallow wells, which Khine thinks may concentrate sunlight; the discovery could help make solar cells more efficient. "We haven't come close to pushing the limits of this technology yet," she says. *—Elizabeth Svoboda*

INTERNET

MICHAEL BACKES, 31

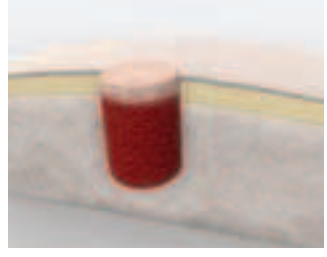
SAARLAND UNIVERSITY

Proving that Internet security protocols can really be trusted

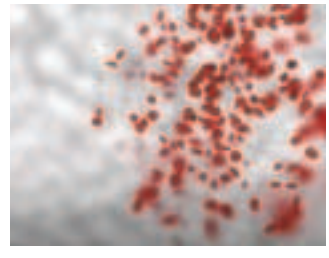
PROBLEM: To help protect Internet users' privacy, cryptographers have developed zero-knowledge proofs, which allow users to demonstrate that they know, say, a password or bank-account number without actually revealing what it is. IBM, Intel, and Hewlett-Packard have used these proofs as the basis for a new Internet security protocol, similar to the Secure Sockets Layer that protects e-commerce transactions. But while the proofs themselves are secure, it's hard to be sure that the protocols based on them are free of glitches that could allow them to be hacked.

SOLUTION: Software designed by Michael Backes, a professor in the information security and cryptography group at Saarland University in Saarbrücken, Germany, can prove in less than a second whether an Internet protocol is truly secure. The program, the first one that's been able to test protocols based on zero-knowledge proofs, creates simplified mathematical representations of the proofs and evaluates how they work within the protocol. The result is that it can efficiently check to see whether individual instructions in a protocol might let an interloper into the system. *—Neil Savage*

A surgeon drills a small hole in the surface of a bone like the knee joint.

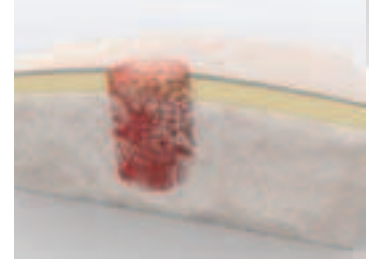


A cylindrical plug of the scaffold is inserted into the hole.



Blood containing stem cells derived from bone marrow impregnates the scaffold. The plug's structure and composition guide the cells to become either bone or cartilage.

Andrew Lynn's biodegradable scaffold mimics the composition of both bone (bottom half) and cartilage (top half) to help heal damaged joints.



As the scaffold degrades, newly formed bone and cartilage cells replace it, repairing the joint.

BIOETCHNOLOGY

Andrew Lynn, 32

ORTHOMIMETICS

Repairing joints by stimulating regrowth in bone and cartilage

ANDREW LYNN wants to phase out metal joint replacements by coaxing the human body to rebuild damaged bone and cartilage. Lynn, CEO and cofounder of Orthomimetics, in Cambridge, England, developed a biodegradable scaffold that a surgeon can implant into any joint weakened by injury or age.

Microscopic pores draw blood cells and stem cells into the plug-shaped scaffold, which is made of collagen and glycosaminoglycans, the materials in human cartilage. The part of the plug that extends into the bone also contains calcium phosphate, which is found in bone. The stem cells take cues from those materials to grow into bone or cartilage where appropriate, repairing the damage as the plug slowly dissolves. The scaffold is already approved for use in Europe, and Orthomimetics is performing more trials to gain approval from the U.S. Food and Drug Administration, which it anticipates in about two years. Scaffolding designed to regrow tendons and ligaments is also a couple of years away. *—Neil Savage*

PADDY MILLS (BACKES); BRYAN CHRISTIE DESIGN (LYNN)

BIOTECHNOLOGY

Jorge Conde, 32

KNOME

Offering consumers whole-genome sequencing—and software to interpret it

THANKS TO Jorge Conde, anyone can have his or her genome sequenced and scoured for clues to future health—all for just under $100,000. Conde is the driving force behind Knome, a personal-genomics startup founded in 2007 that is the first to offer whole-genome sequencing directly to consumers. The approach sets Knome apart from other consumer genomics companies, which analyze just a fraction of an individual's DNA for a few hundred dollars.

Conde, Knome's cofounder and CEO, thinks that the commercial value in personal genomics will lie less in sequencing itself than in interpretation. So the company has developed software to manage, protect, and analyze genetic data; the software combs online databases for the latest scientific findings that have been validated, ranks their relevance, and then uses them to probe an individual's DNA sequence for helpful information.

While Knome's service is still unaffordable for most people, the cost of DNA sequencing is plummeting—from millions of dollars in 2006 to tens of thousands in 2009. Conde believes that when the price of genome sequencing eventually lands within reach of the average consumer, possibly within the next five years, Knome's whole-genome focus will put it far ahead of other companies. *—Emily Singer*

SURFING THE GENOME Knome's browser software allows customers to scan the full sequence of their genomes for genetic variations that increase (highlighted in red) or decrease (highlighted in green) the risk for a number of diseases. Users can scan their entire genomes (top) or focus on a single chromosome—or even specific portions of a chromosome (bottom).

SOFTWARE

SHAHRAM IZADI, 33

MICROSOFT RESEARCH U.K.

An intuitive 3-D interface helps people manage layers of data

SHAHRAM IZADI wants to make interacting with computers more natural. For one of his touch-based interfaces, the research scientist has improved on Microsoft's already impressive touch table, Surface, to present information in a completely new way.

Surface projects infrared light and detects its reflection from fingers or other objects that are on or above a screen, enabling users to work with data displayed on the screen. Izadi's variation, called SecondLight, uses a second projector and a switchable diffuser to add another physical layer of data.

The system projects one image on the table's surface and a second, hidden image above it; passing a semiopaque object over the table reveals the second image. For instance, a user who holds a sheet of paper over an image of a human body might see the bones of the skeleton. Ultimately, Izadi envisions specialized tablets that could interact with SecondLight to facilitate collaboration; doctors working on the same patient, for example, could each add or view new data. *—Kristina Grifantini*

DOUBLE VISION Beneath the screen are liquid crystals that rapidly switch from transparent to opaque. Two projectors underneath send out images in sync with the switching; in this case, the night sky appears on the table, with constellation names appearing above.

COURTESY OF MICROSOFT RESEARCH (IZADI); COURTESY OF KNOME (CONDE)

HUMANITARIAN OF THE YEAR

José Gómez-Márquez, 32

INNOVATIONS IN INTERNATIONAL HEALTH, MIT

Practical medical devices for use in poor countries

José Gómez-Márquez's lab at MIT seems to be part toy store, part machine shop, and part medical center. Plastic toys are scattered across the bench tops, along with a disassembled drugstore pregnancy test, all manner of syringes, and a slew of fake body parts. Coffee filters have been transformed into paper-based diagnostics; a dime-store helicopter provides the design for a new asthma inhaler; even a toilet plunger has been put to use, rigged with tubes and glue to form a makeshift centrifuge.

"Centrifuges break down all the time," says Gómez-Márquez, spinning the plunger's wooden handle in his hands. That's a problem for health-care workers, because even simple medical tests rely on the devices to separate molecules in a blood or urine sample. In rich countries, the broken equipment is quickly repaired or replaced; in the poor countries where Gómez-Márquez often works, finding replacement parts can be impossible, rendering the equipment useless. So he's tried to use readily available materials to make simple versions that are either easy to fiddle with, disposable, or unlikely to break in the first place. "This one could work even without power," he says of the plunger-cum-centrifuge.

Gómez-Márquez, a native of Honduras, is a talented tinkerer: "My mother used to say my toys would last only a few days because I would take them apart, saying I had detected a defect," he recalls. But he is also an inventor on a mission. "When you grow up in a developing country," he says, "you get the sense that fancy technology is expensive to replace, so it often doesn't get replaced."

In his few short years in the field, Gómez-Márquez has gained a reputation among Boston medical-device researchers for his insight into a wide array of design issues. "There are not many people out there that have as broad a view of innovative technology in low-resource settings," says Kristian Olson, a physician at Massachusetts General Hospital in Boston and leader of the Global Health Initiative at the Center for Integration of Medical and Innovative Technology. "He finds a need and then a technology to fit that need. It's a remarkable way of approaching technology development for poor people."

Some might say that Gómez-Márquez was born to improve medical technology. In 1976, when prenatal ultrasound was not available to his mother's doctor in Honduras (it was just catching on in the United States), the physician mistakenly concluded that she was carrying twins and miscalculated how far along she was in her pregnancy. She was induced to give birth in what was actually her seventh month, and Gómez-Márquez—no twin in sight—was born with the numerous health concerns typical of an underweight and premature infant. He escaped any long-term damage. But thanks to a childhood spent in and out of doctors' offices, he developed a profound sense of how important health care was, how capricious access to it could be, and how much medical devices could do to improve it.

It helped, too, that he comes from a medical family. His grandfather, a surgeon, worked at both private and public hospitals in Tegucigalpa, the capital of Honduras, where Gómez-Márquez saw firsthand the differences that money made in access to medical services. Poor people, who went to the public hospital, were less likely to get chemotherapy or appropriate prostheses. "People who could afford it would go to Texas or Boston for their health care," he says.

Gómez-Márquez left Honduras in the late 1990s to attend college in the United States. But his education was sidetracked by Hurricane Mitch, which devastated Honduras in 1998. With his parents in Tegucigalpa no longer able to help pay his tuition, he began working a variety of jobs to support himself—"sometimes the late shift, sometimes regular shifts, sometimes cool stuff, and sometimes humbling stuff." He eventually ended up at Worcester Polytechnic Institute in Massachusetts. "Quite frankly, it was very hard," he says. "I wouldn't recommend that path to anyone."

What little free time he had was devoted to his real interest—combining aspects of different technologies to make them do new things. In 2005, the fledging inventor joined a team participating in MIT's IDEAS competition, which aims to develop new technologies or programs that will have a positive impact on the world. His team focused on developing technologies for health care, inspired by a call from the World Health Organization (WHO) for new ways to deliver the measles vaccine; the disease, though nearly eradicated in the United States, still kills 500 people a day worldwide, mostly children. Gómez-Márquez and his coworkers decided to develop a needle-free system for use in poor countries.

Photographs by STEVE MOORS

IMAGINATION
Inventor José Gómez-Márquez gets much of his inspiration from his assortment of toys and cheap gadgets.

NO TOYS Gómez-Márquez is working on a number of new inhaler technologies for use in poor countries. A disposable cartridge for inhalable vaccine (top left) could make it easier to inoculate children against measles. A plastic helicopter (top right) inspired a new approach to delivering asthma medicine to children. And a paper spacer (center) to use with inhalers provides an easy and disposable way to get more medication into the lungs.

JULIAN PACAUD (DUNKELS)

Administering injectable vaccines takes training, and his team wanted "a device that would allow any community health-care worker, rather than a trained nurse, to give a dose of vaccine," Gómez-Márquez says. While needle-free vaccination systems already existed, most relied on aerosolization technology that is cumbersome and requires electricity.

After examining prototypes of new kinds of devices from drug delivery and engineering firms, Gómez-Márquez quickly decided that existing approaches were much too complicated. "The device was sitting in a fancy box in eggshell foam," he says of one prototype he studied. "If it needs foam to survive a trip to New England, it's never going to make it to Central America."

Taking inspiration from the disposable cartridges used in ink-jet printers, Gómez-Márquez's team designed individual vaporizers preloaded with the correct dose of vaccine; the devices could be used once and then thrown away. The team also developed a way to stabilize the vaccine within the cartridges, eliminating the need for cold storage. Other researchers who've worked on vaccine nebulizers have tried to modify asthma nebulizers, which are not disposable or cheap. "If the aerosolizing head broke, the machine had to be sent back," Gómez-Márquez says. "In our case, because it's just 10 cents, you can throw the broken one away and pull another one out of the box." Most nebulizers also require a power source to run the compressor, which converts liquid medicine into vapor. Gómez-Márquez's team made sure their system can be powered by multiple sources, such as a foot pump, when electricity isn't available.

The resulting device won an Award for International Technology at the IDEAS competition in 2006. "That gave me the idea that I could really do this for a living,"

SOFTWARE

ADAM DUNKELS, 31

SWEDISH INSTITUTE OF COMPUTER SCIENCE

Minimal wireless-networking protocols allow almost any device to communicate over the Internet

ADAM DUNKELS, a senior scientist at the Swedish Institute of Computer Science, has developed software that's used to network devices as diverse as satellites, pipelines, electric meters, and race-car engines. Such devices often incorporate tiny computers that need to relay data to a central server. Using the Internet Protocol (IP) would allow them to communicate with any other device or computer by means of existing infrastructure. But until Dunkels proved otherwise, many computer scientists believed that these "embedded systems" had too little memory and power to use IP.

In 2000, Dunkels shrank the protocol so that wireless sensors could use it to report hockey players' vital signs to fans. He continued condensing it so that ever more limited sensors could use it, eventually writing a version that uses only 100 bytes of RAM. This miniature version of IP is now used by hundreds of companies.

He went on to incorporate it into a complete operating system for embedded systems; called Contiki, the freely downloadable open-source system was first released in 2003. Dunkels is still improving Contiki and finding new ways of using it to build and enhance wireless sensor networks. —*Erica Naone*

Gómez-Márquez says. The team is still improving the device, with funding from the U.S. National Institutes of Health.

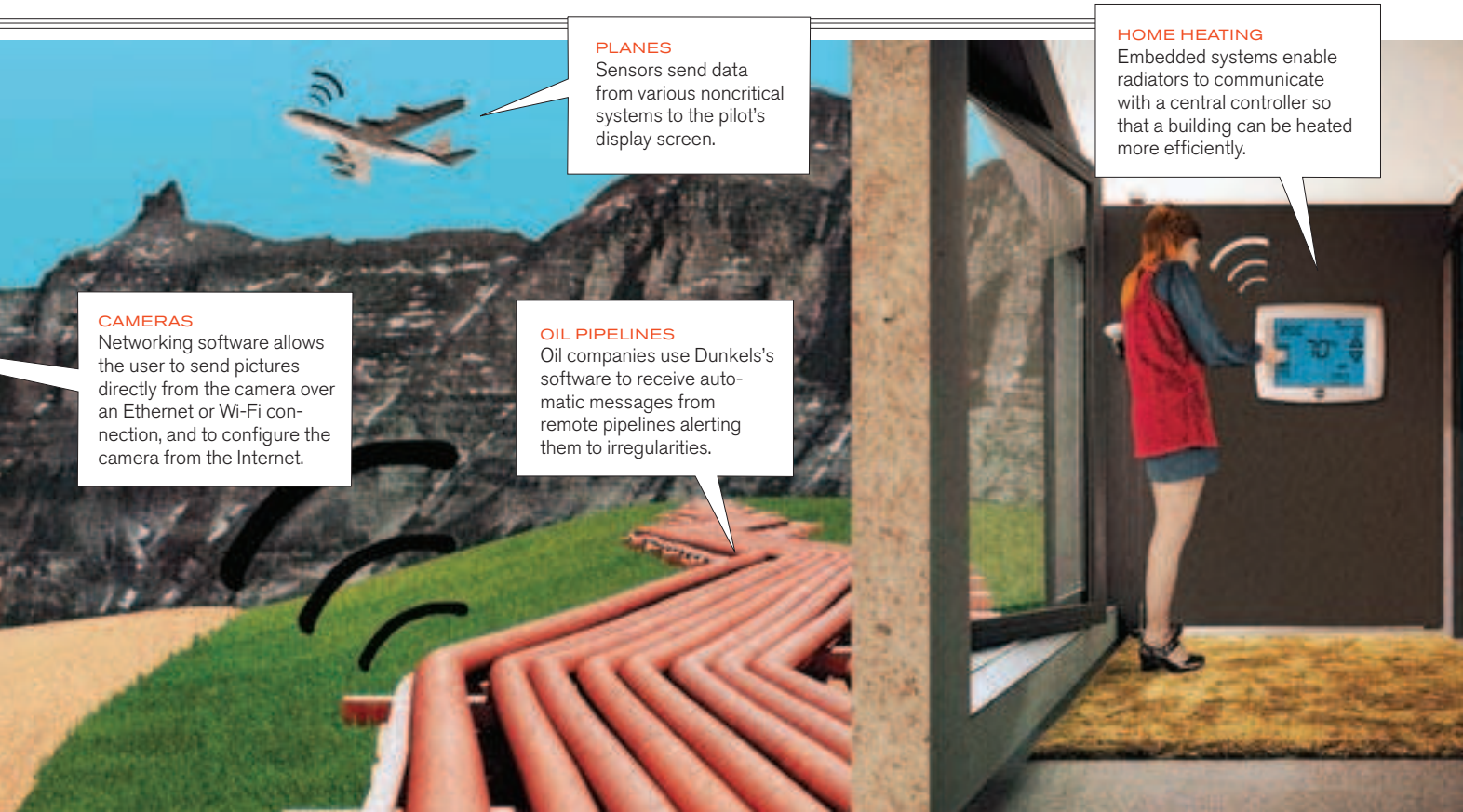
Gómez-Márquez and a team entered the IDEAS competition again the next year, this time focusing on strategies to improve drug compliance in tuberculosis treatment. Though TB can be treated with antibiotics, the disease killed 1.8 million people in 2007, according to WHO estimates, and 9.3 million new cases were diagnosed the same year. One of the biggest challenges in treating TB is making sure that patients stick with the lengthy course of medication required to clear the infection from the body.

A number of new technologies for monitoring drug compliance are being tested, but most of them rely to some degree on self-reporting; for example, patients may be given a phone number to call when they've taken their medicine. "I was the cynic," says Gómez-Márquez. "Patients had no incentive to tell us if they didn't take their drugs." His team developed a simple paper-based test that can be used in conjunction with an incentive program. The test strip is made from layers of coffee filters impregnated with chemicals that react with metabolites of the TB drug in urine, revealing a unique code. The patient texts the code to a central database every day to earn cell-phone minutes. The team launched a trial of the system in Karachi, Pakistan, earlier this year.

Amy Smith, cofounder of the International Development Initiative at MIT, was so impressed with Gómez-Márquez that she hired him to run the Innovations in International Health program, also at MIT, in 2007. He has since built a network of collaborators in countries around the world who can tell him about their populations' health-care needs. That kind of consultation, which lies at the heart of Gómez-Márquez's philosophy, reflects a growing trend in the field of appropriate technology: collaborating early on with the people who will use the devices. "José is really at the forefront of that," says Catherine Klapperich, director of the Biomedical Microdevices and Microenvironments Laboratory at Boston University. "Who is the customer, what do they want, what are they willing to use? You can't assume the answers—that's one of the things José teaches his students and his colleagues."

Gómez-Márquez aims to push this approach even further by encouraging physicians and scientists in poor countries to design their own devices. He is now creating development kits for medical technology—sort of like Erector sets for medical professionals—which will initially be used in Nicaragua. The kits will enable doctors and medical students to devise diagnostics, drug delivery devices, microfluidic chips, and more.

At least, that is the theory. But will busy medical professionals find the kits helpful? Are they too complicated to use or—conversely—too simple to yield useful technology? Gómez-Márquez and his students brought some to Nicaragua over the summer to find out. His hope is that the kits will help a new culture of invention take root. In the long term, it's this kind of approach that could truly revolutionize both medical care and technology in poor countries. —*Emily Singer*



ENERGY

CYRUS WADIA, 34

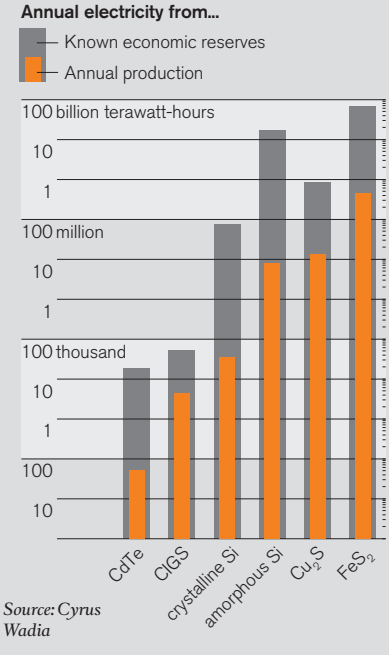
LAWRENCE BERKELEY NATIONAL LABORATORY

Identifying materials that could be unexpectedly useful in solar cells

SOLAR POWER simply won't be able to supply the terawatts of power we need until we identify better materials for solar cells. Silicon, which is used in most photovoltaics, is too expensive; the materials used to make cheaper thin-film solar cells, such as cadmium telluride, are rare—and some are toxic. To uncover other options, Berkeley Lab researcher Cyrus Wadia did an economic analysis of materials that have good electrical properties and can efficiently absorb sunlight. His results point to two previously overlooked materials: iron pyrite and copper sulfide. The analysis shows that the costs of extracting these compounds from existing reserves are low: less than .000002 cents per watt for iron pyrite and .0014 cents for copper sulfide. Wadia has since developed ways to synthesize pure nanoparticles of each. He's made functional but, so far, low-efficiency solar cells from the copper sulfide nanoparticles and is working on iron pyrite cells. *—Katherine Bourzac*

POTENTIAL ENERGY

Abundant materials could supply more solar electricity than cadmium compounds or silicon



Source: Cyrus Wadia

COURTESY OF TXTEAGLE (EAGLE)

TELECOM

Nathan Eagle, 32

SANTE FE INSTITUTE

Mining mobile-phone data for the public good

NATHAN EAGLE, a research fellow at the Santa Fe Institute in New Mexico, believes that mobile phones offer more than a way to communicate. In his hands, they can provide windows on the social structure of communities, information that can lead to better public-policy decisions, and unexpected sources of income for people in poor countries.

For years, Eagle has been mining cell-phone data captured by service providers around the world. Using algorithms he developed as a graduate student at MIT, he strips all identifying information from call logs and looks for patterns in where people go and how they use their phones—patterns that can reveal how social networks are affected by outside forces. For instance, he is working with city planners in Kenya and Rwanda to understand how slums grow and change in response to events such as natural disasters and declines in crop prices. And earlier this year, Eagle began using phone-derived data to build a more accurate model of the spread of malaria in Africa. Previous models had relied on spotty information about people's movements, collected in sporadic surveys. With a better picture of how the disease spreads, governments can improve the policies designed to fight it.

In February, he launched Txteagle, a service that lets any company send cell-phone users simple tasks such as text translation. Participants are paid with credits that can be used for phone service or redeemed for cash at special kiosks. A pilot program in Kenya paid a few cents per task and was too successful for its own good. Within hours of its launch, the ranks of users swelled into the thousands; within days, all the tasks were exhausted.

Eagle plans to relaunch the service later this year in Kenya and other countries, including Rwanda, Indonesia, and the Dominican Republic, with two changes that he hopes will make it sustainable: capping the amount of money a person can make in a day, so that completing tasks becomes more like a hobby than a job, and offering more tasks, such as identifying objects and people in digital pictures or deciphering distorted words from scanned books. *—Kate Greene*

ENERGY

Kurt Zenz House, 31

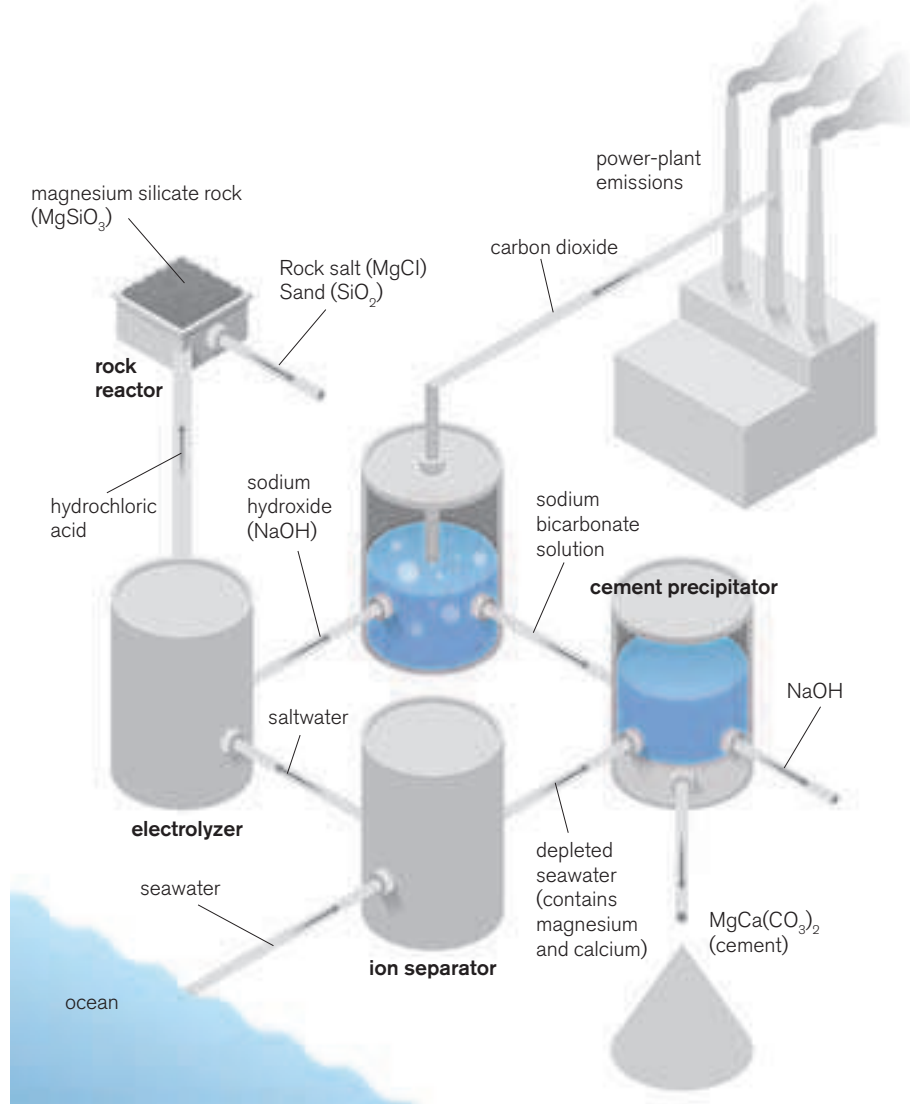
C12 ENERGY

Capturing carbon dioxide through cement production

ABOUT 5 PERCENT of global carbon dioxide emissions come from manufacturing cement. Kurt Zenz House, a research fellow at MIT and cofounder of a startup called C12 Energy, hopes to turn the problem into a solution. He thinks that the carbon dioxide from industrial smokestacks can be captured for use in cement production—keeping it out of the atmosphere for good.

The key to his approach is that alkaline solutions react with carbon dioxide and trap it in various compounds. For example, lye reacts with carbon dioxide to form baking soda. Combining the baking soda with seawater creates a type of cement, the glue that holds concrete together.

House says that regulations designed to limit greenhouse-gas emissions, such as a carbon tax, could eventually make this process profitable as well as environmentally sound. Meanwhile, he's researching other ways to store carbon dioxide, including sequestration under the ocean and in geologic reservoirs on land. And at C12, he's developing technology to reduce the cost of storing carbon dioxide. *—Kevin Bullis*



TURNING CARBON INTO CEMENT Kurt House has a simple recipe: Start with seawater. Extract the sodium chloride from the other minerals to make salt water. Electrolyze that, splitting the water and salt to form sodium hydroxide (lye) and hydrochloric acid. Neutralize the acid in a reaction with silicate rocks, producing sand and magnesium chloride, which can be used together or separately to melt ice on roads. Combine the highly alkaline sodium hydroxide solution with carbon dioxide streaming from a smokestack, trapping the carbon dioxide in the form of baking soda (sodium bicarbonate). Add the baking soda to seawater, which contains magnesium and calcium. The soda triggers a series of reactions, precipitating a magnesium and calcium carbonate that can be used as cement.

TELECOM

ASHOKE RAVI, 32

INTEL

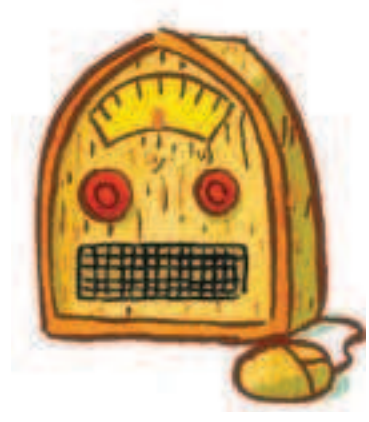
Using software to send diverse radio signals

WITH ASHOKE RAVI's help, future cell phones and netbooks won't need separate circuits to transmit multiple radio signals (over a cellular network, Wi-Fi, and WiMax, for example); a single transmitter will handle them all.

Radios that use software to receive signals over different wireless protocols exist already, but progress has lagged on the transmission side. Much of the difficulty has involved building amplifiers that can cope with the different power levels needed to transmit over the varied distances typical of different wireless networks.

Ravi, a researcher at Intel, built a software-controlled transmitter that solves the problem. Instead of changing the power level to transmit different signals, its amplifier can attenuate or boost the outgoing signal by combining the output of two oscillators that operate at a constant power level. His design allows the amplifier to be optimized for a single power level, increasing battery life.

Ravi expects devices incorporating the technology, such as laptops capable of switching seamlessly between 3G and Wi-Fi networks, to be on the shelves within five years. *—Stephen Cass*



ARTHUR MOUNT (HOUSE); MARC ROSENTHAL (RAVI)

INTERNET

JEFFREY BIGHAM, 28

UNIVERSITY OF ROCHESTER

Free service to help blind people navigate the Web

PROBLEM: More than 38 million people worldwide have low or no vision. To use the Web, many use screen readers, which speak on-screen text aloud. But this software is expensive and is rarely installed on public computers in libraries or cybercafés; in such places, simple tasks such as confirming flight information or checking e-mail can be impossible for blind users.

SOLUTION: As a graduate student at the University of Washington, Jeffrey Bigham created WebAnywhere, a free screen reader that can be used with practically any Web browser on any operating system—no special software required. Users start at webanywhere.cs.washington.edu; from there, they can use keyboard commands to navigate to any Web page. While other screen readers synthesize speech from text locally, WebAnywhere fetches speech from a central server and sends the audio to the user's computer. "The potential is there for big lag times between when the user presses a button and gets speech back," says Bigham, now an assistant professor in computer science at the University of Rochester. "Pretty much everyone thought that this latency problem would kill us." To speed things up, he created a model that predicts which parts of a page a user is most likely to interact with, such as links, and preëmptively fetches audio describing that content. The result is that WebAnywhere sends synthesized speech to users within a fraction of a second. —*Stephen Cass*

HARDWARE

Aydogan Ozcan, 30

UCLA

Inexpensive chips and sophisticated software could make microscope lenses obsolete

EXPENSIVE, BULKY LENSES have been the basis of imaging technology for centuries. Now, says Aydogan Ozcan, an assistant professor of electrical engineering, "it's time to change our thinking." By writing sophisticated image-processing software and taking advantage of the inexpensive light sensors now ubiquitous in cell phones, he may have made lenses obsolete. The lensless imaging devices that Ozcan has built achieve roughly the same resolution as standard bench-top microscopes (about a micrometer), so they can be used to count, identify, and even image living cells.

He's made prototypes mounted in cell phones to demonstrate the technology and has started a company called Microskia to develop it. The first products are likely to be simple microscopes that plug into a cell phone or laptop through a USB cord and display the magnified images on their screens; the first uses will probably be in remote medical centers, to diagnose anemia, cancer, and infectious diseases such as malaria. According to Ozcan, though, his prototypes are actually good enough to replace the large, expensive cell counters used in U.S. hospitals. —*Katherine Bourzac*

PADDY MILLS (BIGHAM); CHRISTOPHER HARTING (OZCAN)

SOFTWARE

Anat Levin, 31

WEIZMANN INSTITUTE OF SCIENCE

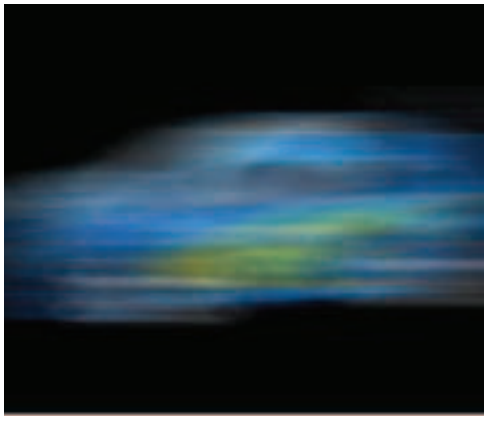
New cameras and algorithms capture the potential of digital images

ALTHOUGH a digital camera is an impressive piece of equipment, it's the same in its basic design as the old-fashioned film camera: a lens focuses an image on a plane. The digital camera simply captures that image with a light-sensing chip instead of film. Anat Levin thinks we can do more.

Levin, a senior scientist at the Weizmann Institute in Rehovot, Israel, is at the forefront of computational photography. She develops ways to manipulate digital images, both inside the camera and on computers. And increasingly, she is exploring new camera designs. "Before digital photography, we would capture images onto a film, and the film was more or less the end of the story," she says. "Now, with digital photography, what we have on the camera is not the end of the process."

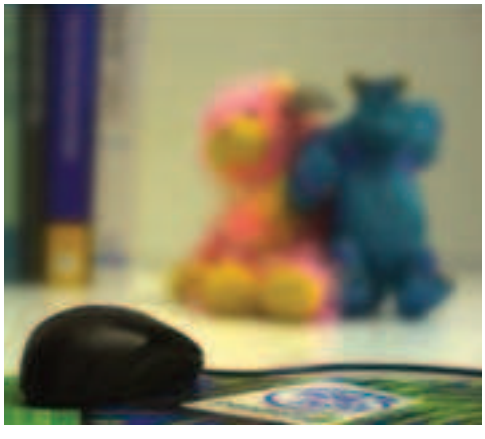
Last year, Levin invented a camera and algorithm that, together, remove motion blur from an image. Paradoxically, the camera moves its sensor horizontally at a varying speed while the image is being exposed, which of course makes the whole image blurry. However, the camera's movement is specially designed to blur the moving and static parts of a scene equally, and by a known amount. Thus, she can use a relatively simple algorithm to remove the blur from all objects. A separate computer processes the image today, but a production model of the camera could eventually do the processing onboard.

Working with colleagues at MIT, Levin has also proposed a lens design that would give a camera greater depth of field, increasing the amount of a scene—near and far—that can be brought into focus at the same time. Square pieces cut from lenses with different focal lengths are superimposed over the regular lens. Each square focuses on an area a different distance from the camera. Using the information from all the lenses, Levin can recalculate the entire image to increase the depth of field, or even refocus on objects that are closer or farther away after the picture has been taken. *—Kurt Kleiner*



NO MORE BLUR The blurry image of a moving toy car was taken with a traditional camera. The clear image was taken with Levin's modified camera. The camera's sensor moves from side to side during exposure, blurring all moving and stationary objects equally, no matter how fast each object is moving. Levin developed an algorithm that can remove this uniform blur to yield a clear image.

Source: "Motion-Invariant Photography" by Levin, Sand, Cho, Durand, Freeman.



A NEW FOCUS Levin and colleagues designed a lattice of different lenses that can be placed over a camera's regular lens. Each lens focuses on an area a different distance from the camera. Using data from all the lenses, Levin can choose which part of the photo is in focus. In the image at left, the mouse is in the plane of focus and looks sharp. On the right, she has moved the plane of focus to the figurines in back.

Source: "4D Frequency Analysis of Computational Cameras for Depth of Field Extension" by Levin, Hasinoff, Green, Durand, Freeman.

PROTECTOR
Computer scientist Dawn Song is arming programmers with better tools to defend computers against malware.

SOFTWARE

Dawn Song, 34

UNIVERSITY OF CALIFORNIA, BERKELEY

Defeating malware through automated software analysis

FOR YEARS, says Dawn Song, computer defenders have been reacting to each new virus, worm, or other piece of malware after it appears, developing and deploying filters that detect known patterns in malicious code in order to stop its spread. Instead of stopping malicious programs one by one, Song, an associate professor of computer science, aims to protect computers at a deeper level.

Source code for both malware and commercial software is often not available, which slows the hunt for vulnerabilities. Song figured out how to find security flaws by examining only the *1*s and *0*s that the computer runs. Her platform, BitBlaze, analyzes malware and automatically generates a filter to protect against it until a security patch is released. It can also analyze those patches and produce new malware that exploits any vulnerabilities; this allows programmers to make security patches as sound as possible.

Such tasks "were previously relegated to highly specialized manual labor," says Avi Rubin, technical director of the Johns Hopkins University Information Security Institute; he calls BitBlaze "a giant step forward in the battle against those who wish harm against computer systems." For example, if a worm tried to infiltrate a computer, BitBlaze's response could fend off a variety of future attacks targeting the same vulnerability. Technology spun out of Song's research has already been incorporated into Google's Chrome browser, and she has collaborated with security software companies such as Symantec. *—Erica Naone*

HARDWARE

Shwetak Patel, 27

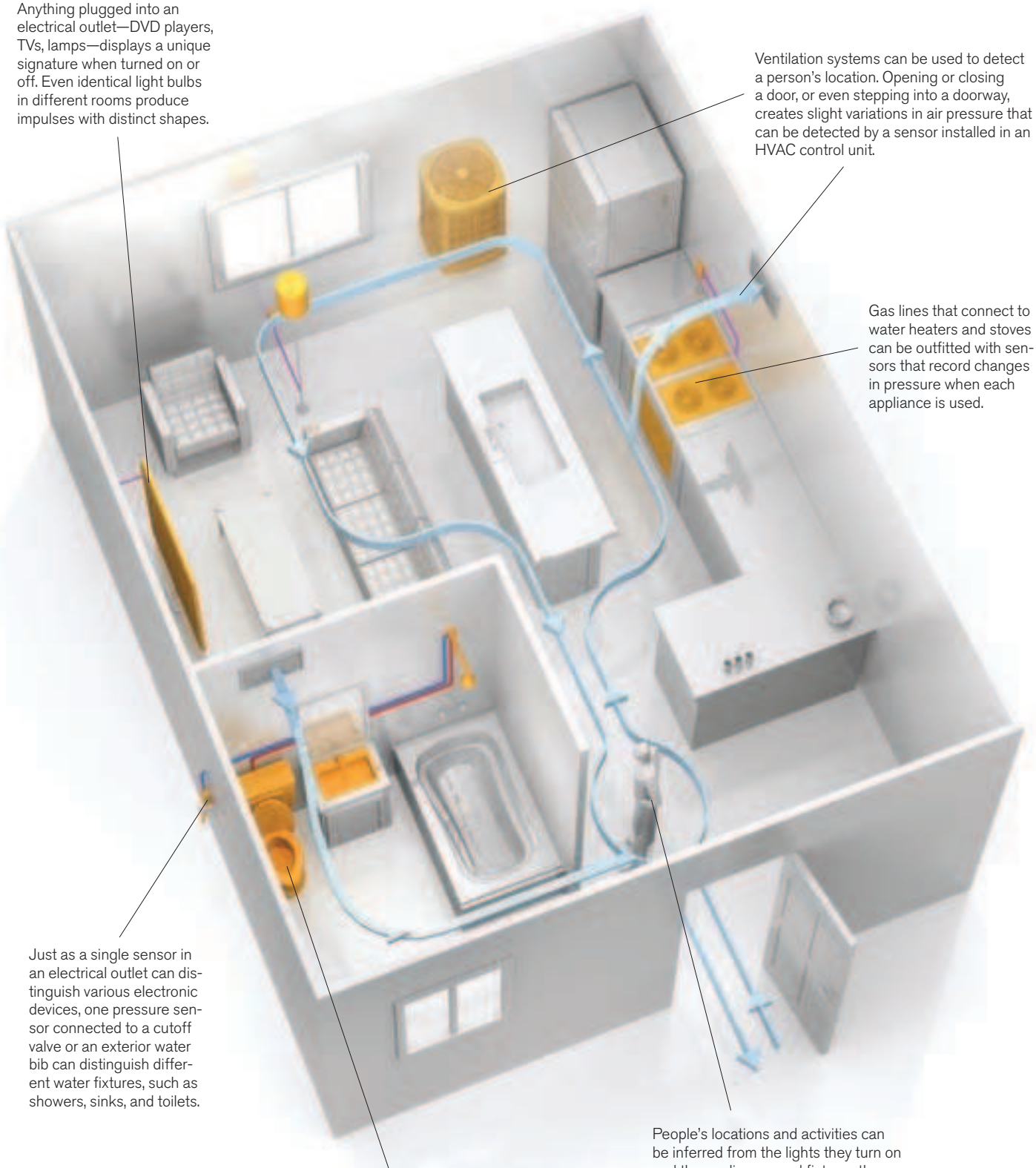
UNIVERSITY OF WASHINGTON

Simple sensors to detect residents' activities

WALLS *CAN* TALK, and Shwetak Patel, an assistant professor of electrical engineering, captures their stories: tales of how people move through their homes and how they use electricity, gas, and water. Patel has shown that each electrical appliance in a house produces a signature in the building's wiring; plugged into any outlet, a single sensor that picks up electrical variations in the power lines can detect the signal made by every device as it's turned on or off. This monitoring ability could be particularly useful for elder care, but there was previously no practical way to achieve it, because it would have required numerous expensive sensors.

Last year, Patel did something similar with ventilation systems, designing a sensor that detects subtle changes in air pressure when a person leaves or enters a room. More recently, he's shown that slight pressure changes in gas lines and water pipes betray the use of specific appliances or fixtures, such as a stove or faucet. Patel believes that providing people with information about their patterns of resource consumption can help them reduce it. He has cofounded a startup that will provide consumers with utility bills itemized by appliance. *—Kate Greene*

JEN SISKA



Anything plugged into an electrical outlet—DVD players, TVs, lamps—displays a unique signature when turned on or off. Even identical light bulbs in different rooms produce impulses with distinct shapes.

Ventilation systems can be used to detect a person's location. Opening or closing a door, or even stepping into a doorway, creates slight variations in air pressure that can be detected by a sensor installed in an HVAC control unit.

Gas lines that connect to water heaters and stoves can be outfitted with sensors that record changes in pressure when each appliance is used.

Just as a single sensor in an electrical outlet can distinguish various electronic devices, one pressure sensor connected to a cutoff valve or an exterior water bib can distinguish different water fixtures, such as showers, sinks, and toilets.

Even identical toilets in different parts of the house produce distinct pressure signatures in the plumbing.

People's locations and activities can be inferred from the lights they turn on and the appliances and fixtures they use. This information could be used to monitor elderly or infirm people without employing a complicated collection of expensive motion sensors.

BRYAN CHRISTIE DESIGN

HARDWARE

PRANAV MISTRY, 28

MIT

A simple, wearable device enhances the real world with digital information

RETRIEVING INFORMATION from the Web when you're on the go can be a challenge. To make it easier, graduate student Pranav Mistry has developed SixthSense, a device that is worn like a pendant and superimposes digital information on the physical world. Unlike previous "augmented reality" systems, Mistry's consists of inexpensive, off-the-shelf hardware. Two cables connect an LED projector and webcam to a Web-enabled mobile phone, but the system can easily be made wireless, says Mistry.

Users control SixthSense with simple hand gestures; putting your fingers and thumbs together to create a picture frame tells the camera to snap a photo, while drawing an @ symbol in the air allows you to check your e-mail. It is also designed to automatically recognize objects and retrieve relevant information: hold up a book, for instance, and the device projects reader ratings from sites like Amazon.com onto its cover. With text-to-speech software and a Bluetooth headset, it can "whisper" the information to you instead.

Remarkably, Mistry developed SixthSense in less than five months, and it costs under $350 to build (not including the phone). Users must currently wear colored "markers" on their fingers so that the system can track their hand gestures, but he is designing algorithms that will enable the phone to recognize them directly. *—Brittany Sauser*

SAM OGDEN

SOFTWARE

Adrien Treuille, 30

CARNEGIE MELLON UNIVERSITY

Complex physics simulations that can run on everyday PCs

MINI MODEL Adrien Treuille creates realistic simulations that can run in close to real time on ordinary PCs. His simulations of airflow (above) have been adapted for use on live TV.

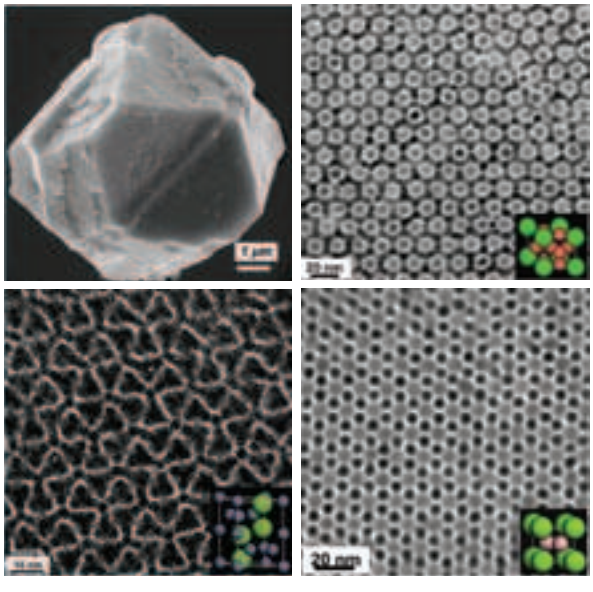
ADRIEN TREUILLE creates simulations of physical processes ranging from the flow of people in a crowd to the motion of proteins in a cell. And while his models are stunningly realistic, what's truly amazing is that they run not on supercomputers but on ordinary PCs. "I want to place curling smoke in the palm of your hand," he says.

To make this possible, Treuille, an assistant professor of computer science, streamlines the mathematical representation of a scenario, removing unlikely outcomes. For example, he says, a full simulation of how a shirt might be folded would include fantastic origami-style shapes. In most cases, a simulation would need to cover only ordinary creases.

Treuille's simulations have attracted commercial interest. For example, ESPN used his techniques to simulate the airflow around NASCAR vehicles on live TV. And Electronic Arts has licensed his crowd-simulation techniques for its games, where they're replacing more processing-intensive artificial-intelligence methods.

But Treuille's work has applications beyond entertainment. He and colleague Seth Cooper designed a downloadable game called Foldit that allows players to fold and tug on simulations of known proteins to design new molecules. More than 90,000 users have registered and played since the game's launch in May 2008. Treuille wonders if someone—perhaps even an amateur—might someday use Foldit to discover a protein that cures cancer.

—Erica Naone



CREATING ORDER Top left: a crystal made from cobalt-platinum nanoparticles. Clockwise from top right: "superlattices" combining nanoparticles of lead selenide and gold, cadmium selenide and gold, and lead selenide and palladium.

COURTESY OF ADRIEN TREUILLE; COURTESY OF ELENA SHEVCHENKO

NANOTECHNOLOGY

ELENA SHEVCHENKO, 32

ARGONNE NATIONAL LABORATORY

Assembling nanocrystals to create made-to-order materials

ELENA SHEVCHENKO is a master at making nanoparticles and assembling them into precise structures with useful properties. Materials made from the nanocrystals created with her methods could lead to ultra-efficient solar cells, tiny but powerful magnets, superdense hard disks, and faster computers.

Trained as a chemist in Belarus, the University of Hamburg in Germany, and Columbia University in New York, Shevchenko has found better ways to make nanoparticles out of metallic compounds; she's produced lead telluride, cadmium selenide, and cobalt-platinum particles, among others. She has also developed a technique for assembling these nanoparticles into "superlattices," orderly crystal structures. Paul Alivisatos, a nanotech pioneer and interim director of the Lawrence Berkeley National Laboratory, calls Shevchenko "the best grower of nanocrystals in the world today."

Mixing and matching these nanoscale building blocks offers endless possibilities for engineering structures with desired optical, electrical, and magnetic properties. A nanoparticle array of lead telluride and silver telluride, for example, is 100 times as conductive as arrays made of either particle alone. So far, Shevchenko has created dozens of new materials. *—Prachi Patel*

NANOTECHNOLOGY

JAMES CAREY, 32

SIONYX

Using "black silicon" to build inexpensive, super-sensitive light detectors

PROBLEM: Silicon has limitations as an optical material. While devices from digital cameras to x-ray detectors take advantage of its ability to absorb electromagnetic radiation, longer wavelengths of light fly right through it. If engineers could make silicon light detectors that "see" more thoroughly into the visible and infrared spectra, relatively inexpensive silicon could replace the costlier, more exotic materials often used in optoelectronics.

SOLUTION: As a graduate student at Harvard, James Carey made thin, super-sensitive light detectors out of "black silicon"—a material discovered accidentally when his colleagues fired a laser at a silicon wafer in the presence of a sulfur-containing gas. Carey demonstrated that the process did more than turn silicon black: it also gave the material the ability to absorb the longer wavelengths of visible and infrared light that thin layers of traditional silicon can't. What's more, it absorbed every wavelength more efficiently than conventional silicon does.

Carey cofounded SiOnyx in Beverly, MA, to manufacture black-silicon chips for devices such as inexpensive night-vision equipment and infrared surveillance systems. Other potential applications include better cell-phone cameras and cheaper, more sensitive detectors that could lower the x-ray dose needed for advanced medical imaging. *—Anne-Marie Corley*

INTERNET

Vik Singh, 24

YAHOO

Opening up search secrets to spur innovation

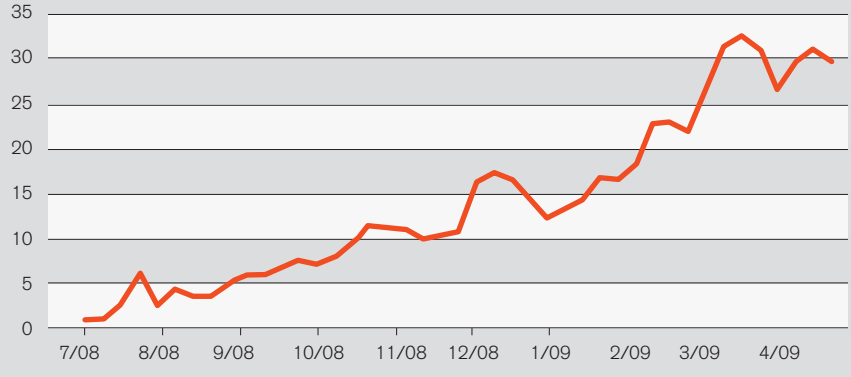
BEGINNING in 2005, Web programmers were able to incorporate results from Yahoo's search engine into their own services, but could do very little with those links: they were limited to 5,000 search queries per day, and they weren't allowed to change how results were ranked or blend their own site's content into the rankings. Then Vik Singh, only seven months out of college and five months into his first job, talked the company into giving away not just the search results but much of the data essential to its relevance formula, such as any tags that identify place names or people. His efforts led to the creation of BOSS (for "Build your Own Search Service"), an application programming interface that lets developers take Yahoo search results and manipulate them to provide services tailored to users' needs, in some cases by considering personal data that a website has collected.

For instance, Singh says, typing *jobs* into Yahoo gives a user links to job-search websites such as Monster.com. But a social-networking site could use BOSS to design a search that considered a user's hometown and current job, or even where his or her friends work.

More than 1,000 developers (of websites, e-mail clients, and mobile-phone applications) have begun using BOSS since its launch in July 2008. The Japanese company Spysee, for example, has built a search engine that finds connections between people, such as common interests or mutual friends, using data it gleans from Yahoo. Such new, smaller search services, Singh says, will create more competition for Yahoo's main rivals, Google and Microsoft, in a market that's otherwise hard to break into. With new services piggybacking on its platform, Yahoo figures it can glean a bigger share of search traffic. That, in turn, will yield data that will help it improve its core search engine. New sites may also mean new revenue for Yahoo, whether from small fees charged for every query or income shared from search-related advertising. Either way, Yahoo expects to improve its own standing by letting other software developers share its wealth of knowledge. *—Neil Savage*

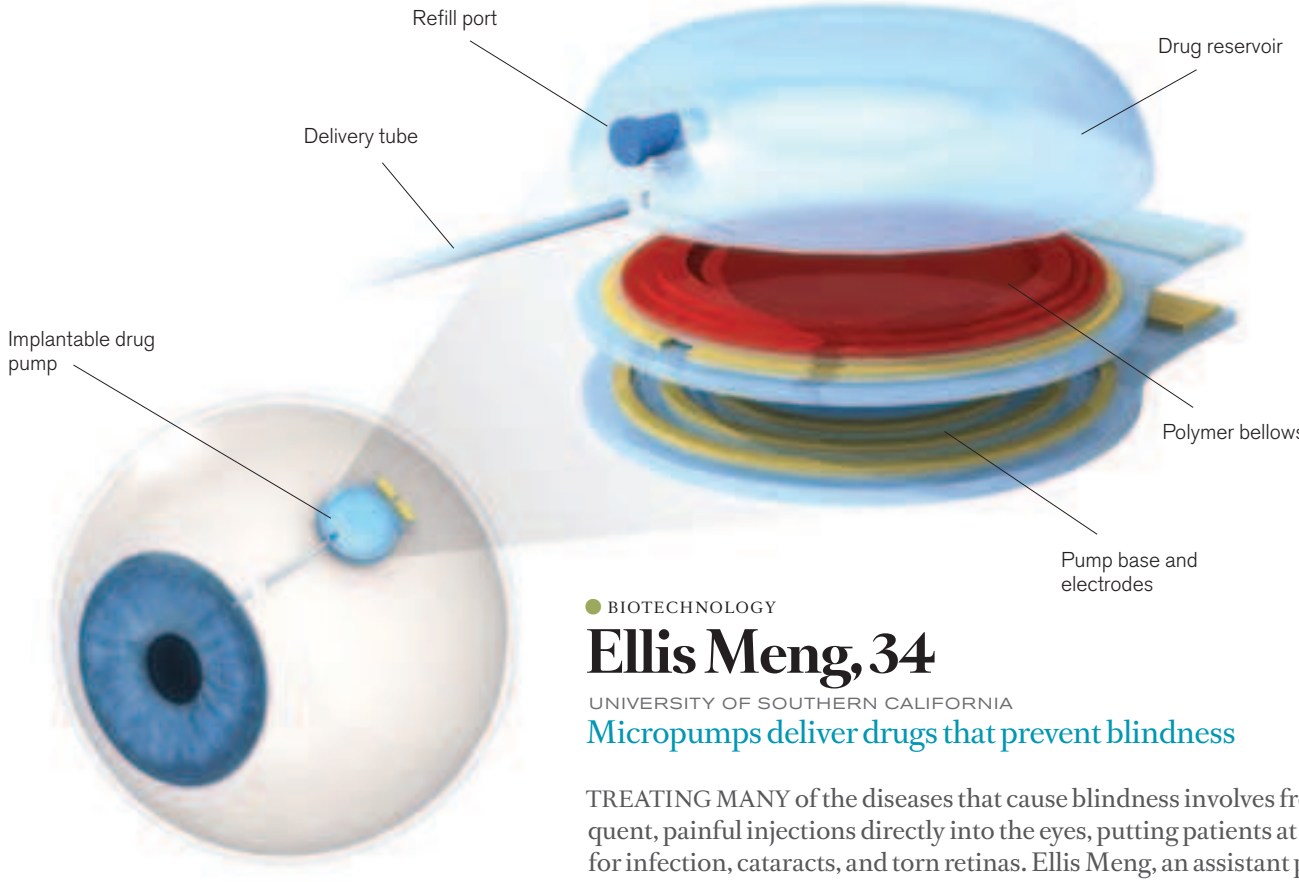
CLIMBING THE CHARTS

By March 2009, the number of queries made through BOSS alone (in millions per day) approached the total search volume on Microsoft's sites.



Source: Yahoo

PADDY MILLS (CAREY)



PRESCRIPTION PUMP Ellis Meng's implantable device for delivering drugs to the eye consists of a chamber that stores the medication; a pump; and a tiny tube that enters the eye. Within the pump, wirelessly powered platinum electrodes produce a current that splits water into hydrogen and oxygen gas, inflating a miniature bellows to force medication out of the reservoir, through the tube, and into the eye.

BIOTECHNOLOGY

Ellis Meng, 34

UNIVERSITY OF SOUTHERN CALIFORNIA

Micropumps deliver drugs that prevent blindness

TREATING MANY of the diseases that cause blindness involves frequent, painful injections directly into the eyes, putting patients at risk for infection, cataracts, and torn retinas. Ellis Meng, an assistant professor of biomedical and electrical engineering, has built an implantable pump to deliver medications more safely.

About the size of a watch battery, her device uses a microfluidic pump to push medications from a reservoir through a small tube and into the eye. A surgeon implants the pump and reservoir on the outer surface of the eye; only the tube enters the eye itself. And unlike existing implants that must be replaced periodically as they run out of drugs, Meng's is refillable. Instead of weekly injections or monthly surgeries, a patient could take just one trip to the operating room, dramatically reducing both pain and risk. Meng is still testing the eye pump in animals but hopes it can be tested in humans within five years. *—Jocelyn Rice*

NANOTECHNOLOGY

ANDREA ARMANI, 31

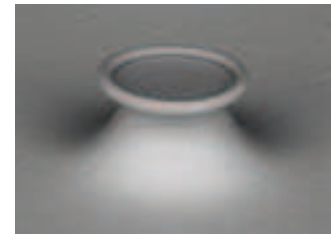
UNIVERSITY OF SOUTHERN CALIFORNIA

Sensitive optical sensors detect single molecules

ANDREA ARMANI, an assistant professor of chemical engineering and materials science, has developed the first optical sensor that can detect single molecules without the use of labels such as fluorescent tags. No label-free detector previously developed has been sensitive enough to distinguish a single molecule.

Armani's sensor consists of a microscopic silica ring that sits on a pedestal atop a silicon wafer. "It's this little, tiny doughnut-shaped device," she says. The ring captures photons from a laser and holds them in orbit. Its surface is chemically treated to snag molecules of the target substance from the surrounding environment. As soon as even one molecule of the compound is ensnared, it creates a detectable change in the ring's optical properties.

Because it works in liquids, including blood, the sensor could be an ideal diagnostic device. Armani envisions, for instance, incorporating one into intravenous catheters that would monitor a patient for infection, picking up telltale molecules in minuscule quantities long before symptoms appeared. *—Jocelyn Rice*



ZEROING IN A tiny doughnut-shaped silica ring atop a silicon wafer acts as an extremely sensitive optical sensor. The ring's optical properties change when even a single molecule binds to it.

BRYAN CHRISTIE DESIGN (MENG); COURTESY ANDREA ARMANI

OurTube

"Open video" could beget the next great wave in Web innovation—if it gets off the ground.

By DAVID TALBOT

In 2005, Michael Dale and Abram Stern, a pair of grad students in digital media arts at the University of California, Santa Cruz, decided it would be fun to make video remixes of speeches in the U.S. Congress. Their goals were artistic; Stern had notions, for example, of editing a Senate floor speech to remove everything but the pronouns. They would be following, loosely, in a tradition of video commentary that includes remixing speeches from the 2004 Republican National Convention to feature only the many utterances of *terrorism* or *September the 11th* by George and Laura Bush, Dick Cheney, Rudy Giuliani, and others. Aware that congressional proceedings are public—and that C-SPAN airs them freely—the pair went online to hunt for the raw material. But "the footage wasn't there," Dale recalls. While C-SPAN did offer archival material for a fee, he says, "if we wanted to pull together a few different clips of senators saying different things—there was no online repository for download."

So they bought a computer and several hard drives, which they hooked up to a television, and started unabashedly copying C-SPAN's congressional coverage. Then, in March 2006, they went live with a website called Metavid.org, hosted by the University of California, which offered the purloined legislative footage free for the downloading. Before long, C-SPAN—a nonprofit company created by the cable industry—claimed that the university was violating its copyright. When university lawyers learned that only the videos of committee hearings had been shot by C-SPAN's cameras (proceedings on the floor of the House and Senate were recorded by government cameras), a compromise was reached: floor footage could stay up (with the C-SPAN trademark removed), but the committee footage had to be taken down. C-SPAN later liberalized its policies to allow free reuse of federal-government coverage—but it excluded commercial use. This is not something Metavid could promise, so the hearings remain unavailable on the site.

As they looked for alternative sources of committee footage, Dale and Stern encountered a thicket of technical problems. It turns out that many (though not all) congressional committees do make their own videos, and some of these committees allow you to play the videos on their websites. But the technologies involved reflect the chaos of competing formats that characterizes Web video today. To pick two examples: the Senate Commerce Committee offers videos in a Flash player but offers no download link. And the House Judiciary Committee still uses RealPlayer, a format that's now largely obsolete. Any would-be users of these resources would soon run into trouble. Where download links weren't provided, they'd need special software to copy the video from the government site. Once the videos were in hand, they'd have to buy software to do any necessary format conversions and editing. And finally, they'd have to upload the results. "All of these offerings are difficult to reuse in a video project," says Dale.

Dale and Stern's difficulties offer one small glimpse into a larger problem with online video: unlike much of the rest of the Web, it is accessed through a collection of closed, proprietary formats, such as Adobe's Flash and Microsoft's Silverlight. (Try a video search engine such as Blinkx; you'll get plenty of videos pulled from around the Web, but to watch them you may need to download or update software.) Certain websites, led by YouTube, convert uploaded content to Flash for ease of viewing. Today, however, a growing number of technologists and video artists want to see Web video adopt the kind of open standards that fueled the growth of the Web at large. HTML, the markup language that describes Web pages; JavaScript, the programming language that allows forms, graphics, and various special effects to be added to them; JPEG, the standard for images—all these building blocks of the Web can be used by anyone, without paying fees or asking permission. This openness was indispensable to the creation and then the explosion of blogs, search engines, social networks, and more.

A similar transformation of video would not just allow trouble-free playback of any video you might encounter. It would also mean that any innovation, such as a new way to search, would apply to all videos, allowing new technologies to spread more rapidly. And

it would make it far easier to mix videos together and create Web links to specific moments in different videos, just as if they were words and sentences plucked from disparate online text sources: imagine linking part of a politician's speech to a contradictory utterance years earlier. "In 1993 people thought AOL's newsrooms were mind-blowing, because that's all they were exposed to," says Dean Jansen, outreach director of the Participatory Culture Foundation, a nonprofit group that is developing an open-source video player called Miro. "Now they can write their own blogs and find and read hundreds of thousands of news sources and blogs, from all over the Internet. I don't think it's an exaggeration to say that this is the scale of change that would become possible if video [technologies] were totally free online, like text and images."

Today, Dale works toward realizing that vision as part of an effort by the Wikimedia Foundation, which launched and operates Wikipedia, to create video companions to the online encyclopedia's text entries. The idea is that you'll be able to search the Web for snippets of video, import them into a Wikipedia article, and keep track of edits—all using open technologies that don't require video plug-ins or software purchases. One hope is that Wikipedia, as the world's seventh-largest website, will help drive video openness generally, says Chris Blizzard, director of technical evangelism at Mozilla, which is supporting the project. But the larger point is that efforts like these will make it far easier for anyone to innovate with video and for anyone else on the Web to enjoy those innovations. The results are impossible to predict, except through the example of what the open Web has provided so far. "Nobody is going to tell you they want something before it emerges," Blizzard says. "Rather, the experience of the Web is: 'Holy cow, I can do this other thing now!' Open standards create low friction. Low friction creates innovation. Innovation makes people want to pick it up and use it. But it's not something where we can guess what 'it' is. We just create the environment that lets 'it' emerge."

LET'S GO CRAZY

YouTube has helped make video a mainstay of the Web, thanks largely to its simplicity and user-friendliness. Anyone can open a YouTube account and upload videos, and anyone who visits YouTube can easily find and watch videos, all free. It has become the world's third-most-popular website, with 41 percent of the video-hosting market. A recent analyst report by Credit Suisse predicts that YouTube will serve up an astonishing 75 billion video streams this year, to 375 million users. And every minute, YouTube's burgeoning servers slurp up 20 hours' worth of newly uploaded user videos, says the company's director of product management, Hunter Walk. Susan Boyle, the Scottish songstress phenom? The latest footage from Tehran's street protests? Bulldogs on skateboards? Your cousin's baby video? It's all there, available in a few clicks.

"The video box that you see on YouTube is a whole bunch of formats inside this plug-in that isn't manipulable, transformable, or remixable in the way everything else on the Web is," says Mozilla's Mark Surman.

And as YouTube grows and adds features, it continues to stress simplicity and user satisfaction (much in the spirit of its current owner, Google, which bought YouTube in 2006 in a deal worth $1.65 billion). Among other features, it has introduced ways for users to add elements such as captioning to their videos, build on their social networks (by automatically alerting Twitter followers when they upload new videos, for example), and annotate videos with computer-readable tags to improve search results. Other new tools can help businesses manage their YouTube-hosted videos and learn who is watching them. "YouTube represents a unique place in the video ecosystem; the breadth, depth, and freshness of content is unparalleled," Walk says. "The best years are ahead of us." In 2009, uploads of videos from mobile devices are up 1,700 percent—400 percent just since the release of the new iPhone 3G, he says. And the only obvious price of such service is exposure to advertising.

Internet video is thriving in other respects, too. Not just YouTube but Apple TV, Windows Media Center, Hulu, and more are making it possible for computers and mobile devices to deliver programming normally associated with television. (YouTube, for example, in a bid for growth and revenue, is offering premium channels with short-form content from entertainment titans Disney, ABC, and ESPN.) Boxee, a New York City startup, is bringing things full circle with a browser that enables you to play any media available over the Internet on your TV screen; the interface is designed for easy use from across the living room.

Against this backdrop, there initially seems little to dislike about YouTube. But its sheer size makes it an easy and tempting target for filtering by national governments (Iran, for one, has done just that). The result is that video can, in some contexts, be censored more effectively than other forms of Web content. Similarly, YouTube is a convenient target for legal action by media

To view a Mozilla demonstration of what open-video could enable and a videographer's take on the technology, take a snapshot of this code with your smart phone (for instructions, see p. 25) or visit **www.technologyreview.com/openvideo**

companies trying to protect copyright, sometimes in ways that overstep the bounds of common sense. Two years ago Stephanie Lenz, a Pennsylvania mother, got an e-mail from YouTube announcing that it had taken down her shaky 29-second movie of her toddler son, Holden, giggling and dancing as the Prince hit "Let's Go Crazy" played distortedly in the background. YouTube explained that it was responding to a request from the Universal Music Publishing Group, which owns the rights to the song. She argued that her video represented "fair use," and it was reposted. But she decided to sue Universal Music, claiming that it was abusing the Digital Millennium Copyright Act. (Universal Music later said it had issued thousands of so-called takedown notices on behalf of Prince alone; the Artist himself is fanatical on the subject.)

While artists have every right to thwart wholesale copying, such crackdowns on incidental, noncommercial use—which is generally quite legal—can inflict collateral damage on innovation. "When people make their own mixes of existing material and YouTube takes that down, this is a huge inhibitor to this kind of commonplace creativity that the Web enables," says Abigail De Kosnik, a professor of new media at the University of California, Berkeley, and author of *Illegitimate Media: Minority Discourse and the Censorship of Digital Remix Culture*. "What people need to realize is that too much of those kinds of protections and [technology] restrictions—and right now, without open video, we have too much of both—inhibits new genres from emerging."

Finally, the need to generate revenue is driving YouTube further toward a centralized, television-like model, with advertising-supported premium content. In short, while it's never been easier for the average Internet user to find and consume video online, you can't easily adapt or reuse what you find in the vast body of video out there. "The video box that you see on YouTube is a whole bunch of different formats inside this plug-in that isn't manipulable, transformable, or remixable in the way that everything else on the Web is," says Mark Surman, executive director of Mozilla. You can't even download videos you play on YouTube—at least not without help from third-party websites or software.

YouTube sees little need to add features such as downloading tools. "We haven't gotten enough feedback that we need downloads," Nikhil Chandhok, a YouTube senior product manager, said at a recent conference in New York City. "You are mostly connected all the time ... and can access any YouTube video you want." Even if you do go to the trouble of using third-party services to download videos, if you want to do anything creative with those videos, your work has just begun. You will need to convert various formats, buy video editing tools, and learn to use them.


OPEN ARCHIVES Wikipedia's new video-collaboration effort will allow editors to mine open-source archives for content, including congressional footage from Metavid.org and diverse collections held by the Internet Archive; its holdings range from Iraq War news coverage to dating-advice videos from the late 1940s and 1950s.

WWW.METAVID.ORG AND WWW.ARCHIVE.ORG

(Walk did not want to talk about open standards, except to say that the company has "been about a lot of kinds of openness early" in terms of expanding access to video itself. Of course, making video easier to work with outside of YouTube would tend to threaten YouTube's dominance.)

WIKIVIDEO

If YouTube is the epicenter of the Web's video revolution, Wikipedia is the epicenter of online collaboration. In the eight years since its founding, it has grown to become not just the dominant online reference but an increasingly important source of real-time news, with more than 13 million frequently updated entries, including 3 million in English. But these two hubs of free, user-generated content operate as if in separate universes. Wikipedia, which makes it easy to alter content, offers few videos to play (though about 3,000 videos can be found scattered around the site). YouTube, with millions of videos available, offers few options for editing or innovating with them. Generally, each site's best qualities as an information resource are all but absent from the other.

OPEN VIDEO IN PRACTICE

How a remix was made—and how it could have been easier

In June, after six months of editing, a New York video artist named Jonathan McIntosh finally released his opus: a six-minute video depicting an ill-fated relationship between lead characters of two unconnected TV shows: *Buffy the Vampire Slayer* and *Twilight*.

Key to this effort, McIntosh says, was finding clips with the right bits of dialogue, so he could figure out how to convincingly interweave them. To do this, he conducted Google text searches of websites, such as twiztv.com, that carry fan-transcribed dialogue. But finding the spots on the videos where the dialogue appeared remained a laborious manual process.

Open video standards could change all that. "My using Google searches on fan transcript websites is just the tip of the iceberg of what would be possible for finding video clips to use," he says. "I could imagine a set of people out on the Web picking through shows like Lou Dobbs or Bill O'Reilly, and building a searchable database of clips where they said various things." Searches for words and dialogue would lead you to the actual video clips containing the dialogue, not just text transcripts; you could then lift these video clips out and patch them together with ease, as if they were text. Over time, websites could arise containing finely honed video-clip archives of statements made by politicians, TV pundits, and pop stars. Other archives might contain thematically or temporally related video clips. This would have saved McIntosh the work of finding clips himself from hours of video.

But as it was, McIntosh's video editing was a long slog. His downloads (using a popular file-sharing application) arrived in a format called .AVI. To make this work more smoothly with his editing software—FinalCut Pro, which costs about $1,000—he converted the raw footage into .MOV using free software called MPEG Streamclip. At the end of the process, he had to compress the finished work—using a type of compression called H246, among others—so that he could upload it to various websites. "I've gotten good at knowing which video software to use, and how, but it took me quite some time," he says. "With open standards, this would become a whole lot easier for casual Internet users."

McIntosh later posted English-language subtitles for his finished work on dotsub.com, whereupon fans around the world eagerly wrote translations—21 in all, most recently Swedish. The video has been watched many millions of times.

McIntosh's video remix occupies a gray area of copyright law, but no media company has attempted to take it down. Arguably, he's given the vampire franchises a better shot at eternal life—in DVD rentals and sales. *—David Talbot*

MONSTER MASHUP A New York video artist relied on fan-created text transcripts of dialogue to help create a video-remix relationship between characters played by Edward Cullen and Sarah Michelle Gellar.

Jonathan McIntosh's remix:
www.rebellionpixels.com

But that could change as Wikipedia strives to add features that permit effortless open-source video editing and remixing. Michael Dale, the former Santa Cruz student, is leading the effort at Wikimedia under the sponsorship of Kaltura, a startup with offices in New York City and Israel. Kaltura is developing open-source technologies for playing, editing, and uploading videos. A major benefit of open video is that the video itself can be extracted from the player, just as an image can be extracted from a website when you right-click it. With the new version of HTML technology, HTML 5, an open-source player is included in the browser—no plug-ins required. Mozilla's newly released Firefox 3.5 browser, Apple's Safari, and Google's Chrome *(see "An OS for the Cloud," p. 86)* all support this feature, though Safari requires a plug-in to support a specific open video format, called Ogg Theora, that Wikipedia is using. And if history is any guide, these advances by competitors may goad Microsoft to follow suit with improvements to Internet Explorer. "Right now, when you post a Flash video, you are posting the video and also a plug-in player, and that can make it difficult to access the video file itself," says Dale. "Once video is just another asset on the Web and something browsers can natively deal with, we can pull audio, video, images, and text from anywhere on the Internet and do the kinds of sharing and editing and remixing that you want to do, all in the open Web platform." Can Wikipedia really change the way everyone uses video? "When Wiki

"Today the video Web is written in tens of languages, causing all the usual barriers," says Suranga Chandratillake, CEO of Blinkx. "With a dominant open format, everything will link to everything else."

started, people said it wouldn't work, but it worked," says Kaltura cofounder Ron Yekutiel. "The next question is: Why should it stop at simple media?"

The results should start to become visible this fall. If you are editing a Wikipedia entry, you will find an "Add media" button. Clicking it will bring up an interface that will, initially, allow you to search through three repositories of free licensed multimedia files. One is Metavid, the congressional archive started by Dale and Stern. Another is the Internet Archive, the San Francisco–based digital library most famous for archiving old Web pages; it also holds hundreds of thousands of old interviews, documentaries, and films contributed from various sources. The third is Wikimedia Commons, a multimedia repository operated by the Wikimedia Foundation itself.

Some observers think Wikipedia's foray into multimedia will help move the entire Web toward open video standards. "To make video part of the fabric of Wikipedia will provide incentives to [video] producers to get their stuff out there and indexed," says Jonathan Zittrain, a Harvard Law School professor and cofounder of the Berkman Center for Internet and Society at Harvard University. Producers who want their videos excerpted and linked on a Wikipedia page—drawing more traffic to their own websites—will not just have to put much less restrictive licenses on the material; they'll also have to accept open standards rather than proprietary ones. "With no business model yet gelled, this is just the right time for Wikipedia to be experimenting, and possibly leading, the development of open tools and content for video," Zittrain says.

Jimmy Wales, Wikipedia's founder, sees the effort as the next logical advance in Web technology. "Today any computer programmer in the world can launch a website and have full-strength tools for creating new things," he says. But he points out that this is not yet true for video. No collaborative video editing process is available to all Web users. "It's a process that's a lot harder to do if all I can do is download a 60-minute video to my computer, open up some [proprietary] software to edit the video, then upload it," Wales says. "There's no easy way for other people to give direct feedback. The record of the edits isn't there. And if someone else wants to change it, they have to redo all the work on their computer."

Wikipedia's effort to promote open video standards isn't the only one; the YouTube competitor Dailymotion, for example, is making 300,000 videos available in the Theora format. But whatever the catalyst, wide acceptance of such standards could have important implications even for people who don't want to make their own video remixes. In particular, it could drive broader and faster advances in video search. Consider Blinkx, which has indexed 35 million hours' worth of videos and devised a variety of ways to search them, from simple means—metadata, or computer-readable tags that literally describe what's in a video—to advanced techniques involving speech analysis and facial recognition. One method devised by Blinkx allows searchers to draw a box around a face in a video, click it, and then search the Web for other videos containing that face. But for that trick to work with all Web videos, Blinkx must rebuild the interface code to accommodate each of a handful of dominant video formats and 80 lesser-used ones. "If open video works, then all the people doing these kinds of innovations within individual video formats—they can all talk to each other," says Suranga Chandratillake, the company's founder and CEO. "It means innovation isn't split into separate groups in separate formats. Today the video Web is written in tens of languages, causing all the usual barriers when you want to switch from one to the next. With a dominant open format, everything will link to everything else; viewers will be able to freely watch content and jump between relevant clips."

And on the copyright front, Creative Commons, the nonprofit organization that has provided usage licenses for 250 million copyrighted works, is helping to clarify what existing video works can and can't be used. "Open licensing is a crucial part of this fairly multilayered ecosystem that will make open video take off," says Mike Linksvayer, Creative Commons' vice president. "If the video itself, and the components of the video, like music, aren't actually openly licensed, then each of the other layers is hindered."

Lately, Mozilla's Blizzard and Surman have been showing off something a Mozilla developer cooked up with open-source video tools. In their video, the two men walk in and out of the camera's field of view. A thought bubble dances over each head (tracking their movements thanks to face recognition software); inside each bubble, their real-time Twitter feeds are displayed. This was all done with Theora, HTML 5, and other new standards, Blizzard says. While such a stunt could be performed with proprietary software, it wouldn't be so easy—or so easily shared. "This is what we mean when we talk about taking video out of the plug-in prison and allowing people to create things," he says. The goal isn't to make any one application possible but to bring about the next Internet revolution—one whose specific form is hard to foresee, except that it's likely to be televised.

And webcast. TR

DAVID TALBOT IS *TECHNOLOGY REVIEW*'S CHIEF CORRESPONDENT.


TEAM AGNI

TEAM AGNI
Arvind Rabadia
and Cedric Lynch

The Electric Acid Test

On the Isle of Man, the beginnings of a marketable electric motorcycle.

By ADAM FISHER

The Isle of Man is a small British possession in the Irish Sea. Inland, a native breed of four-horned sheep graze in verdant fields. On the coasts, castles touch the sea. The Manx have their own (albeit dead) language, their own money, their own laws, and—tellingly for this story—no national speed limit. This quirk of governance makes the place a natural host to a bloody ritual that has taken place nearly every spring for a century: the Tourist Trophy. The TT is not *a* motorcycle race but *the* motorcycle race: the first, the most famous, and by far the deadliest.

It's also a party: 40,000 bikers invade the island determined to scare the wool off the sheep while screaming through the Snaefell Mountain Course, a winding circuit of public roads cordoned off for the event. The circuit climbs from sea level to 1,380 feet, snaking for almost 38 miles through 200-some turns on country roads that cut through village, hamlet, and farm. Much of the track is hemmed in by dry-stacked fieldstone walls topped by spectators drinking their pints. There is no safe place to crash. Racers die or are maimed every year.*

As in warfare, the carnage is accompanied by technological progress. Soichiro Honda came to the race in 1959 having declared five years earlier that it was time to challenge the West. Less than a decade later, his company won the world manufacturer's title in every class: 50cc, 125cc, 250cc, 350cc, and 500cc. Not long after that, the British motorcycle industry was itself conquered, wiped out by mismanagement and superior Japanese technology. Ironically, the technical advances that made racing bikes so fast led the Fédération Internationale de Motocyclisme (FIM), the sport's governing body, to decertify the race in 1976, calling it too dangerous. Thus, pros no longer

**This year is no exception, claiming the life of a racer named John Crellin—the 226th TT fatality.*

Photograph by JUDE EDGINTON

COURTESY OF BRAMMO

> The winner will not just be the fastest in an esoteric class but the front-runner in the greater challenge ahead: creating an electric bike that can compete in the $50 billion world motorcycle market.

ride the TT. However, the race's bloody reputation makes the TT, if anything, even more prestigious than FIM-sanctioned events. To compete in it, in the words of the legendary FIM rider Valentino Rossi, "you need to have two great balls."

This year, the Manx government added a futuristic new event to the June race schedule. The TTXGP, for "Tourist Trophy eXtreme Grand Prix," was billed as the first zero-emissions motorcycle race. While any technology could enter, as a practical matter zero emissions means electric. Even the FIM got on board, making the TTXGP the first FIM-approved TT race in over 30 years and the first officially sanctioned electric-motorcycle race ever. "It is either going to be the most important day in the next hundred years of motorcycling or a complete debacle," said Aaron Frank, an editor for *Motorcyclist* magazine who traveled from Milwaukee to watch the race. "But either way, it's worth watching."

As the day arrives, everyone watching knows that the TTXGP will be slower than the "real" motorcycle race, the TT, because the TTXGP is an energy-limited race. In effect, the "gas tank" of an electric bike is minuscule, so to win the TTXGP the bikers must mind their energy consumption. In contrast, the gas bikers in the TT run with their throttles wide open. However, batteries' energy density has been improving at a rate of about 8 percent a year, which means that even without any other technological progress, electric bikes should run head to head with gas in about 20 years. The TTXGP is intended to make the future arrive sooner. The winner will not just be the fastest in an esoteric class but the front-runner in the greater challenge ahead: creating an electric bike that can compete in the $50 billion world motorcycle market. In that sense, the TTXGP is the proving ground for the next Honda.

GREEN MACHINES

Twenty-two electric bikes show up to compete. While many of the entries are experimental one-offs from technical universities or obsessive hobbyists, three entrants are so-called factory teams: Brammo, Mission Motors, and MotoCzysz. All of them hail from the West Coast of the United States. Brammo is in Ashland, OR, Mission Motors in San Francisco, and MotoCzysz in Portland. And all are entering the consumer market with an electric bike. Brammo is set to sell its motorcycle off the floor at Best Buy: it's a $12,000 runabout with a top speed of 55 miles per hour. For the TTXGP, Brammo has upgraded almost every component in its bike to create two 100-mile-per-hour crotch rockets, both entered in the race. The Brammo racers are fast, light, and nimble but under-spec'd compared with what Mission and MotoCzysz trailer in: full-size race bikes heavy with batteries, capable of reaching 150 miles per hour. The Mission bike will sell for $69,000; the MotoCzysz will probably sell for slightly less.

Mission and MotoCzysz are both targeting the high-end superbike market, and both promise to ship products in the next year or two, but that is where the similarities end. Mission's charismatic young CEO, Forrest North, is a computer geek who likes to speculate on the future of software design: he fantasizes about a wheelie-popping autobalancing "Segway app" for a bike's control computer. (Though he hastens to say that Mission itself is not working on such an app.) MotoCzysz founder Michael Czysz is a designer—and his bike is a looker. Exposed battery packs protrude from each side, a fresh take on the naked-sportbike style of the insanely popular Ducati Monster. The packs are modular and swappable, and the bike is "green," Czysz explains, "because it's upgradable." Even Infield Capital's David Moll, one of the investors behind Mission Motors, is impressed when he sees the battery-as-engine design.

ALSO-RANS The best-looking electric bike in the race (above), from boutique bike builder MotoCzysz, didn't get much farther than the starting line. But even the biggest and best-funded electric-bike company, Brammo, had reliability issues. Only one of the two bikes Brammo entered in the race (opposite) made it all the way around the circuit.

"I've got a dog in this fight, but if *that* doesn't excite you," he says of the MotoCzysz entry, "then there's something wrong with you."

Brammo, Mission, and MotoCzysz are directly competing for the capital that's needed, in enormous quantity, to introduce a new vehicle to the American market. Brammo has the early lead in the money race: a $10 million investment from Best Buy's venture fund and Chrysalix Energy Venture Capital, as compared with Mission's $2 million in seed capital. Bringing up the rear is MotoCzysz, a company essentially funded out of Michael Czysz's back pocket. While both Mission and Brammo hope to win the TTXGP in order to generate publicity and thus orders, MotoCzysz *needs* to win, or at least place, in order to woo enough capital to enter the marketplace. It's anyone's race to win, of course, but in most motor sports, the factory teams with access to deep corporate pockets are the first to cross the finish line. Behind them come the privateers—scrappy dreamers and shade-tree mechanics who are short on resources but long on heart.

So it's all the more surprising that in the week before the race, a dark horse emerges, freaking out all the factory teams. The fastest bike in the TTXGP prelims—two qualifying runs around the island—turns out to be from Team Agni, a total unknown, a mere privateer. Millions of American research-and-development dollars find themselves chasing the tail of a no-money rat-bike engineered in India.

"BLOODY SIMPLE"

Cedric Lynch and Arvind Rabadia are the two halves of Team Agni, and their tent is the smallest in the pit area, a 10-foot-by-10-foot red E-Z Up. Their kit is equally minimal: an assortment of hand tools, a halogen work light, and a few copies of the latest issue of *Battery Vehicle Review* to pass out to curious visitors. The zine, which is the journal of the U.K.'s Battery Vehicle Society, is a hand-stapled, Xeroxed affair; the cover story, "Living with the G-WIZ," features one owner's evaluation of his electric quadricycle.

In their tent the day before the big race, Lynch positions the hot halogen light over a custom fiberglass battery tank that Rabadia has built by hand. The toxic smell of polyester resin fills the air. "Bloody hell, Cedric!" exclaims Rabadia from his lawn chair. "Are you trying to kill us, man?" Rabadia sports a Mohawk and a gold hoop earring, giving him an all-purpose air of menace. Lynch, on the other hand, has the otherworldly demeanor of someone who has spent the past 20 years meditating in a cave. He's barefoot, ponytailed, and dressed in little better than rags; it is unclear whether he even hears Rabadia's outbursts. Right now, Lynch is bent over double, fashioning a part from a piece of scrap metal by holding it with his bare feet and boring a hole in it with a mechanical hand drill. They're quite a pair—the pirate and the pauper. "I do all the talking and Cedric does all the working," Rabadia says. "Swearing at Cedric is my way of calming myself down."

At the center of the Agni tent is the machine that's blown through the two qualifying laps and set the pace to beat. If the factory-made machines look like the future, the Agni entry looks like Frankenstein's monster. The bike is a Suzuki GSX-R with a lopsided stack of lithium-polymer batteries where the internal-combustion engine and gas tank would normally be. Twin DC motors, each the size and shape of a stack of pancakes, are mounted outboard of the frame and drive the rear wheel by way of a chain. The engineering is primitive, the craftsmanship nonexistent. The whole bike seems to be held together with zip ties and duct tape. Instead of a dashboard, the rider reads from a battered yellow voltmeter jammed between the handlebars. After the fiberglass tank dries, the paint job comes out of a spray can, and the stickers of Agni's sponsors—mainly Kokam, a

IAN KERR

South Korean battery company—are slapped on so haphazardly that they flap in a breeze. But Team Agni is ready for the main event.

The bike's shabbiness is, for Rabadia, a badge of honor in what he sees as a class struggle between the factory teams and the privateers. "We thought we were the underdogs," he says. The Agni bike was thrown together in only six weeks. "It could have been half that," he says. "I told Cedric 'two weeks,' but then I wasn't around to crack the whip." For Lynch, the bike's evident ugliness is not a class statement but, rather, the fruit of his rigorous antimaterialist philosophy. To Lynch, it's what inside that's important, and nothing else. There's not much to an electric bike—just a battery bank, controllers, motors, and the wiring that connects them. But unlike all the other designers, who hide their circuit boards inside aluminum cases, Lynch showcases his wiring under Plexiglas right on top of the main battery stack, enabling his competitors to examine exactly what makes the thing go. There's not a microchip to be seen, but that's exactly the point. "Anything that's not there can't go wrong," Lynch explains. He races as he lives, on the barest minimum. "Bloody simple, it is," Rabadia adds. "Nothing to it."

Team Agni may be a study in minimalism and eccentricity, but it also has something formidable: more than 50 years of experience. Lynch recounts how he first became interested in electricity. "I left school when I was 12 because I couldn't stand it, and I went home to read," he says. "Mostly theoretical treatises and that sort of thing." For fun, he puttered around in a workshop with his father, one of the engineers who had built the Colossus computer and broken the Nazis' war codes. As a young man, Lynch made a career of entering electric-vehicle races. The first one was in 1979, when his poverty proved to be no disadvantage. "DC motors were very expensive then," he recalls, "so I made one of my own design out of tin cans." Lynch came in second, as his tin-can design proved to be more efficient than that of the factory-made competition. In the 1980s and '90s he would come to dominate the Battery Vehicle Society races. "We won most of the things we entered," Lynch says. "It was good fun." Back in the BVS days, Rabadia was Lynch's protégé, but now it's Lynch who works for Rabadia. The latter set up Agni in his native India to commercialize his mentor's design: the so-called pancake motor. He's brought Lynch to the TTXGP "because our motor is the best, and we need to get the respect we deserve."

"JUST A MISCALCULATION"

Meanwhile, on the opposite side of the island, Team MotoCzysz has rented out a small test track to get some last-minute performance data. Things are not looking good for the best-looking bike. In the first qualifying lap around the island, MotoCzysz blew two of its three motors, and in the second, the rider had to cross the finish line under human power, paddling with his feet like a duck. "Humiliating," Czysz admits, "but just a miscalculation."

Like Agni's machine, the bike has no software, no onboard data-logging computer, no odometer. The bike is smart enough to know how much charge it has left, but the state-of-charge meter—the "gas gauge," in essence—had yet to be calibrated. To make sure that the bike has enough juice for the race, the rider has to know what's left in the "tank." And without a dynamometer, the only way to get the calibra-

IAN KERR

UNDERDOG Arvind Rabadia (above), of the came-from-nowhere Team Agni, wears the Indian flag as a cape in the winner's circle. Agni's home-brew bike (left) crushed the flashy, high-design, high-technology bikes of the American teams with a keep-it-simple strategy.

tion information is to ride the bike in a circle for a few miles and then hook it up to a digital multimeter. Czysz makes the best of it while climbing onto the bike. In full leathers, highly styled hair, and designer sunglasses, he looks like the Derek Zoolander of electric-vehicle racing. He even speaks with Zoolanderian opacity: "Other teams have data acquisition," he boasts. "We have rider acquisition."

Adrian Hawkins, the lead MotoCzysz engineer, sheepishly holds up his stopwatch and ledger. "Our acquisition system," he says.

Just before launch, the owner of the track—a practical joker—suggests to Czysz that Imperial miles and U.S. miles are different.

Czysz turns to Hawkins, and asks how long each lap is.

"One point five miles," answers Hawkins.

"U.K. miles or U.S. miles?" Czysz quizzes.

Hawkins is stumped: U.K. miles or U.S. miles?

"U.K. miles or U.S. miles!" Czysz demands, more forcefully this time. Czysz has a reputation as a screamer, and his voice is rising.

"U.S. miles," Hawkins stammers, gently telling Czysz that miles are consistent across borders.

A voice from the small crowd that's gathered to watch comes to Hawkins's rescue, politely informing Czysz there's an Imperial gallon and a U.S. gallon, and perhaps that is the source of his confusion.

"It's gallons that are different?" says Czysz to no one in particular, "Okay, I didn't know." And with that, he zips off.

THE BREAKDOWN LANE

Mission has even bigger problems. Like MotoCzysz, its bike completed one of the qualifying laps and broke down in the other—but the team has no idea why. It's the night before the big race, the one that counts; the bike is busted, and all Mission really knows is what its rider Tom Montano can describe. The bike was feeling really good—fast, even, he says. He was passing other riders left and right, and then the machine just gave out. "All I can compare it to," Montano says, "is when a gas bike starts lugging and then binds up."

Hearing this, Jon Wagner, Mission's CTO, gets on his hands and knees and opens the bike's power plant. It sits low in the bike's frame just forward of the swing arm. "I'm getting a sinking feeling that we've got a jenky motor," Wagner says. Placing the two probes of a digital multimeter to the motor's guts, he takes three measurements of internal resistance: .018 ohms for the first and .021 ohms for the second two. The measurements are consistent with a short in one of the three windings. "We may have to take this thing apart and relacquer the coils," he concludes.

Wagner has found the failure, but that doesn't explain why the motor quit in the first place. Mission was counting on its custom software to give it an edge, but forget stunts like "Segway mode"—the Mission bike didn't even have brains enough to shunt current away from an overheating motor. Even worse, when data-acquisition tech Ray Shan downloads the race log from the bike, he finds that Mission would have been better off if it hadn't used a race computer at all. "We completed 31 percent of the track before we broke down," says Shan, in disbelief, "but we used 40 percent of our total power." Even if the motor hadn't blown, the bike would have run out of juice before the end of the qualifier.

It's Seth LaForge, Mission's lead software engineer, formerly of Google, who starts to connect the dots. What if the software loaded on the ride computer was not updated to account for the larger sprocket that was swapped onto the back wheel before the race? Then the bike would be running faster than its speedometer would indicate—and this would explain why Montano reported passing other riders left and right.

To test LaForge's hypothesis, Shan recalculates the bike's speed by extrapolating from the tachometer data. Since electric bikes generally don't have gearboxes, the relationship between rotor speed and actual speed is fixed. The revised speed calculations indicate that the bike was topping 100 miles per hour for the first seven miles of the course—an energy-guzzling pace, for sure. But why didn't the bike just run out of charge before the finish, like the MotoCzysz bike? Why did it break down instead? The answer comes when Shan superimposes the corrected speed data onto a motor efficiency map. "One hundred miles per hour is right at the edge of the chart," says LaForge, gasping a little when he sees the graph. The bike was redlining the entire way, dumping energy in the form of heat. A faulty setting in the motor control software was feeding the motor too much electricity. The bike just cooked itself.

LaForge would be a hero, except it's his code that didn't account for the larger gear in the first place. Garbage in, catastrophic motor failure out. The team works all night to replace the motor.

"OVER THE MOON"

On Friday, race day, the spectators at the start/finish line are in a jocular mood. They've come to the Isle of Man to see the afternoon's Senior TT, the "real" race, in which the boys with the biggest balls

race thundering liter bikes at speeds of up to 180 miles per hour. Although the fastest TTXGP bikes can hit 150 miles per hour, they can't sustain that pace for the whole course, because even the biggest, heaviest battery bombs in the field—Mission and MotoCzysz—have the energy equivalent of only about a quarter of a gallon's worth of gasoline in their tanks. The electric racers must carefully modulate their throttles to conserve energy. For the TT traditionalists, that fact makes the electric race little more than a mildly amusing morning diversion. Voices from the crowd crack jokes:

"That isn't the warm-up area anymore, then, is it?"

"No more 'Gentlemen, start your engines!' I suppose."

"They'll need some pretty long extension cords for this track."

And then, with a wave of a green flag, the electric bikes take off, not an extension cord in sight. The motors wind up, accelerating the bikes with a steadily rising whir: mix, chop, blend, crumb, aerate—until, finally, puree. They're so quiet that some spectators camped out on the sides of the road aren't even aware the bikes are coming until they're already past.

The motors wind up with a steadily rising whir: mix, chop, blend, crumb, aerate—until, finally, puree. They're so quiet that some spectators aren't even aware the bikes are coming until they're already past.

It's a good show, especially when some of the field start blowing parts under the strain. MotoCzysz is the first casualty: two of its three air-cooled DC motors disintegrate, throwing chunks of metal through its vent holes. The machine, perhaps fittingly, comes to rest in front of one of the oldest churches on the island—St. Runius. Back at the start/finish line, Michael Czysz realizes that he's a goner when the radio announcers at the first checkpoint fail to note his bike. "That's it, that's it, it's over now," he says under his breath as the meaning of failure sinks in. One of Brammo's two hopped-up race bikes is the next casualty, victim of a bump taken at 100 miles per hour that pops the rear wheel in the air ever so slightly. Suddenly free of the earth's bite, it spins even faster, the motor's RPM skyrockets, and the overclocking sensor inside does what it was programmed to do: cut the power to protect the engine. The bike eventually gets to within one mile of the finish line before giving up the ghost completely.

The rest of the pack zooms by, chains clicking furiously, on the way to their next checkpoint, the Sulby speed trap. A privateer team from Germany, XXL, pours on the juice to ring up the race's fastest recorded top speed: 106.5 miles per hour. XXL's English-speaking engineer, Marko Werner, laughs at the grandstand crowd's stunned reaction when they hear the figure over the PA. "It vas easy," Werner says. There were no all-nighters or last-minute track days for him or his team, because instead of trying to reinvent the electric wheel, XXL spent its time and money—four months and 35,000 euros—sourcing the most trouble-free components it could find: a water-cooled motor and controller designed for a 10-year-old hybrid car, the Audi A4 Duo. "Siemens did all the verk," Werner confides.

The race is not won by top speed, of course—it's the fastest average speed that counts. And Agni is first over the finish line with a lap time of 25 minutes, 53.5 seconds. A cry goes through the grandstand crowd: "India wins!" Three minutes behind, for second place, is XXL. Brammo's good bike takes third, the only factory bike to make it to the podium. Mission comes in fourth, and MotoCzysz and the second Brammo bike are DNF: did not finish.

If the TTXGP were a battle in which the biggest war chest determined the outcome, Brammo would have won. If it were a beauty contest, MotoCzysz would have taken the tiara and the sash. If it were chess with a crash helmet, then Mission would have had it. But in the end, reliability trumped all. Agni won the TTXGP by keeping it simple. XXL and Mission both used faster but more complicated liquid-cooled AC motors. But second-place XXL chose the tried-and-true design from Audi, while fourth-place Mission went all-out with a custom-built power plant. The experience of third-place Brammo is most telling of all: its one and only breakdown came *after* it bolted on an extra battery pack at the last minute.

As the Agni, XXL, and Brammo bikes glide one-two-three into the winner's circle, a scene of barely controlled mayhem erupts: the riders are draped with laurels, and shouts of "Motoguru!" go up for Cedric Lynch, who tells the television cameras that he is "absolutely delighted" with the result. Magnums of champagne are uncorked and sprayed across the crowd. TTXGP race organizer Azhar Hussain toasts Team Agni with a speech: "Today, a new company with no budget and no baggage came and won." The Indian ambassador to the United Kingdom is on hand to give Team Agni his personal congratulations. Arvind Rabadia receives him while wearing the Indian tricolor as a superhero-style cape. "First in the qualifier, first in the second qualifier, first in the race," boasts Rabadia, the Ashoka Chakra embroidered on his flag looking for all the world like a motorcycle wheel. "I'm over the moon, man!"

Lynch sees the race differently, as he does most things. In his mind, he didn't beat the rest of the field. Rather, he led it, earning a historic victory in an epic, ongoing struggle against internal combustion. "I can just imagine," Lynch muses, "what the petrolheads would have said if we *hadn't* beaten the 50cc lap record set in 1966 by Ralph Bryans on a Honda works bike." TR

ADAM FISHER IS A FREELANCE WRITER WHO LIVES IN SAUSALITO, CA. HE GAVE UP MOTORCYCLING FOR GOOD AFTER CRASHING HIS SPARKLE-ORANGE 1974 HONDA CB750.

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An Operating System for the Cloud

Google is developing a new computing platform equal to the Internet era. Should Microsoft be worried?

By G. PASCAL ZACHARY

From early in their company's history, Google's founders, Larry Page and Sergey Brin, wanted to develop a computer operating system and browser.

They believed it would help make personal computing less expensive, because Google would give away the software free of charge. They wanted to shrug off 20 years of accumulated software history (what the information technology industry calls the "legacy") by building an OS and browser from scratch. Finally, they hoped the combined technology would be an alternative to Microsoft Windows and Internet Explorer, providing a new platform for developers to write Web applications and unleashing the creativity of programmers for the benefit of the masses.

But despite the sublimity of their aspirations, Eric Schmidt, Google's chief executive, said no for six years. Google's main source of revenue, which reached $5.5 billion in its most recent quarter, is advertising. How would the project they envisioned support the company's advertising business? The question wasn't whether Google could afford it. The company is wonderfully profitable and is on track to net more than $5 billion in its current fiscal year. But Schmidt, a 20-year veteran of the IT industry, wasn't keen on shouldering the considerable costs of creating and maintaining an OS and browser for no obvious return.

Finally, two years ago, Schmidt said yes to the browser. The rationale was that quicker and more frequent Web access would mean more searches, which would translate into more revenue from ads. Then, in July of this year, Schmidt announced Google's intention to launch an operating system as well. The idea is that an OS developed with the Internet in mind will also increase the volume of Web activity, and support the browser.

Google's browser and OS both bear the name Chrome. At a year old, the browser holds a mere 2 to 3 percent share of a contested global market, in which Microsoft's Internet Explorer has a majority share and Firefox comes in second. The Chrome operating system will be released next year. Today, Windows enjoys around 90 percent of the global market for operating systems, followed by Apple's Mac OS and the freeware Linux. Does Google know what it's doing?

RITUALIZED SUICIDE

Going after Microsoft's operating system used to be hopeless. When I covered the company for the *Wall Street Journal* in the 1990s, I chronicled one failed attempt after another by software innovators to wrest control of the field from Bill Gates. IBM failed. Sun failed. Borland. Everybody. By the end of the 1990s, the quest had become a kind of ritualized suicide for software companies. Irresistible forces seemed to compel Gates's rivals, driving them toward self-destruction.

The networking company Novell, which Schmidt once ran, could have been one of these casualties. Perhaps Schmidt's managerial experience and intellectual engagement with computer code immunized him against the OS bug. In any case, he knew that the task of dislodging Microsoft was bigger than creating a better OS. While others misguidedly focused on the many engineering shortcomings of Windows, Schmidt knew that Microsoft was the leader not for technical reasons but for business ones, such as pricing practices and synergies between its popular office applications and Windows.

So for Schmidt to finally agree to develop an OS suggests less a technological shift than a business revolution. Google's new ventures "are game changers," he now says.

What has changed? Google has challenged the Microsoft franchise, further diminishing a declining force. The latest quarter gave Microsoft the worst year in its history. Revenue from its various Windows PC programs, including operating systems, fell 29 percent in the fiscal quarter that ended in June. Some of the decline

Illustration by BRIAN STAUFFER

stems from the global economic slowdown. But broad shifts in information technology are also reducing the importance of the personal computer and its central piece of software, the OS. In many parts of the world, including the two most populous countries, China and India, mobile phones are increasingly the most common means of reaching the Web. And in the rich world, netbooks, which are ideal for Web surfing, e-mailing, and Twittering, account for one in every 10 computers sold.

Another powerful trend that undercuts Microsoft is toward programs that look and function the same way in any operating system. "Over the past five years there's been a steady move away from Windows-specific to applications being OS-neutral," says Michael Silver, a software analyst at the research firm Gartner.

One example would be Adobe Flash. Such popular social applications as Facebook and Twitter are also indifferent to operating systems, offering users much the same experience no matter what personal computer or handheld device they use. Since so many people live in their social-media sites, the look and feel of these sites has become at least as important as the user interface of the OS. The effect is to shrink the role of the OS, from conductor of the orchestra to merely one of its soloists. "The traditional operating system is becoming less and less important," says Paul Maritz, chief executive of VMware, who was once the Microsoft executive in charge of the operating system. By and large, he has noted, "people are no longer writing traditional Windows applications."

Microsoft's troubles make the company's OS doubly vulnerable. Vista, its current version, has been roundly criticized, and it has never caught on as widely as the company anticipated; many Microsoft customers continue to use the previous version of Windows, XP. A new version being released this fall, Windows 7, promises to remedy the worst problems of Vista. But even 7 may not address a set of technical issues that both galvanize Microsoft's critics and stoke the appetites of Brin and Page to create a more pleasing alternative. In their view, the Microsoft OS takes too long to boot up, and it slows down even the newest hardware. It is too prone to viral attacks and too complicated.

Exactly how Google plans to solve these problems is still something of a mystery. Technical details aren't available. Google has said so little about the innards of its forthcoming OS that it qualifies as "a textbook example of vaporware," wrote John Gruber on his blog Daring Fireball. Information is scarce about even such basic things as whether it will have a new user interface or rely on an existing open-source one, and whether it will support the driver that make printers and other peripherals routinely work with Windows PCs.

The mere announcement of Chrome already threatens Microsoft, however. The imminence of Google's entry into the market—following the delivery of its Android OS for mobile phones—gives Microsoft's corporate customers a reason to ask for lower prices. After all, Google's OS will be free, and the buyers of Windows are chiefly PC makers, whose profit margins are already ultra-slim.

"It's all upside for Google and no downside," says Mitchell Kapor, a software investor and the founder of Lotus, a pioneer supplier of PC applications that was bloodied by Microsoft in the 1990s.

LEGACY CODE

Fifteen years ago, I wrote a book on the making of Windows NT—still the foundation of Microsoft's OS family. At the time, I wrongly concluded that developing the dominant operating system was proof of technological power, akin to building the greatest fleet of battleships in the early 20th century, or the pyramids long ago. Windows NT required hundreds of engineers, tens of millions of development dollars, and a huge marketing effort. By the mid-1990s, Microsoft was emphasizing features over function, complexity over simplicity.

In doing so, Microsoft and its cofounder, Bill Gates, seemed to be fulfilling the company's historical destiny. The operating system as a technological showpiece goes back to OS/360, a program designed by IBM that was immortalized in *The Mythical Man-Month*, a book by the engineer Frederick Brooks. The historian Thomas Haigh explains, "That was a huge scaling up of ambition of what the OS was for."

IBM's 360 mainframe was the first computer to gain widespread acceptance in business, and the popularity of the machine, first sold in 1965, depended as much on its software as its hardware. When IBM used Microsoft's DOS as the operating system for its first PC, introduced in 1981, it was the first time Big Blue had gone outside its own walls for a central piece of code. Soon, technologists (including, belatedly, IBM) realized that control of the OS had given Microsoft control of the PC. IBM tried and failed to regain that control with a program called OS/2. But Microsoft triumphed with Windows in the 1990s—and became the most profitable company on earth, turning Gates into the world's richest person. Thus, the OS came to be viewed as the ultimate technological product, a platform seemingly protean enough to incorporate and control every future software innovation and at the same time robust enough to drag outdated PC machines and programs into the present.

It couldn't last. The main reason why control of the OS no longer guarantees technological power, of course, is the ascent of the Internet. Gates made few references to the Internet in the first edition of his book *The Road Ahead*, published in November 1995. Neither Windows NT nor its mass-market incarnation, Windows 95, was intimately connected to the Web. With the spread of Netscape's browser, though, Gates began to realize that the individual PC and its operating system would have to coöperate with the public information network. By bringing a browser into the OS and thus giving it away, Microsoft recovered its momentum (and killed off a new generation of competitors). Then, preoccu-

pied once again with control of the OS, Microsoft missed the sudden, spectacular rise of search engines. When Google's popularity persisted, Microsoft was unable to do with the search engine what he had done with the browser.

In one sense, this failure to adapt to a networked world reflected the integrity of Gates's vision of the PC as a tool of individual empowerment. In the mid-1970s, when the news of the first inexpensive microprocessor-based computers reached Gates at Harvard, he instantly understood the implications. Until then, computers had been instruments of organizations and agents of bureaucratization. The PC brought about a revolution, offering the little guy a chance to harness computing power for his personal ends.

Technology is now moving away from the individualistic and toward the communal—toward the "cloud" *(see our Briefing on cloud computing, July/August 2009)*. Ray Ozzie, Microsoft's chief software architect, who has been the most influential engineer at the company since Gates retired from executive management, describes the process under way as a return to the computing experience of his youth, in the 1970s, when folks shared time on computers and the network reigned supreme. Cloud technologies "have happened before," he said in June. "In essence, this pendulum is swinging." Similarly, Schmidt recalls how, in the early 1980s, Sun Microsystems' OS was developed for a computer that lacked local storage.

The return to the network has big implications for the business of operating systems. Computer networks used to be closed, private: in the 1960s and '70s they revolved around IBM mainframe operating systems and, later, linked Windows machines on desktops and in back rooms. Today's computer networks are more like public utilities, akin to the electricity and telephone systems. The operating system is less important. Why does Google want to build one?

Successful operating-system designs continue to pay off big, though increasingly in cases where the system is well integrated with hardware. Apple's experience is illustrative. For years, people advised Steve Jobs, Apple's cofounder and chief, to decouple the Mac OS from the company's hardware. Jobs never did. Indeed, he moved in the opposite direction. With the iPod and then the iPhone, he built new operating systems ever more integrated with hardware—and these products have been even more successful than the Macintosh. "For Apple, software is a means to an end," says Jean-Louis Gassée, who once served as the company's chief of product development and who has since founded his own OS and hardware company, Be. "They write a good OS so they can have nice margins on their aluminum laptop."

The effort to create a good OS carries risks. The biggest one for Google is that expectations will outstrip results. Even though the company plans to use a number of freely available pieces of computer code—most notably the Linux "kernel," which delivers basic instructions to hardware—its new system can't be assembled, like a Lego plaything, out of existing pieces. Some pieces don't exist, and some existing ones are deficient. There is the real chance that Google might tarnish its reputation with an OS that disappoints.

Today's computer networks are more like public utilities, akin to the electricity and telephone systems. The operating system is less important. So why does Google want to build one?

Then there is the risk that cloud computing won't deliver on its promise. Privacy breaches could spoil the dream of cheap and easy access to personal data anywhere, anytime. And applications that demand efficient performance may founder if they are drawn from the cloud alone, especially if broadband speeds fail to improve. These unknowns all present substantial threats.

MAGIC BLENDS

David Gelernter, a computer scientist at Yale University, has described the chief goal of the personal-computer OS as providing a "'documentary history' of your life." Information technology, he argues, must answer the question "Where's my stuff?" That stuff includes not only words but also photos, videos, and music.

For a variety of good reasons—technical, social, and economic—the cloud will probably never store and deliver enough of that "stuff" to render the OS completely irrelevant. You and I will always want to store and process some information on our local systems. Therefore, the next normal in operating systems will probably be a hybrid system—a "magic" blend, to quote Adobe's chief technology officer, Kevin Lynch. Predicting just how Microsoft and Google will pursue the magic blend isn't possible. "We hope we are in the process of a redefinition of the OS," Eric Schmidt told me in an e-mail. But one thing is certain: the new competition in operating systems benefits computer users. Microsoft will do more to make Windows friendlier to the new networked reality. No longer a monopoly, the company will adapt or die. It's worth remembering that in the 1970s, AT&T, then the most powerful force in the information economy, "made a set of decisions that doomed it to slow-motion extinction," says Louis Galambos, a historian of business and economics at Johns Hopkins. "Microsoft is not immune to 'creative destruction.'"

Neither is Google. To completely ignore operating systems in favor of the cloud might be an efficient route to failure. And there is much to admire in the very attempt to create a new one. For Brin and Page, it is as much an aesthetic and ethical act as it is an engineering feat. TR

G. PASCAL ZACHARY WROTE *SHOWSTOPPER* ON THE MAKING OF WINDOWS NT.

Technology Review's Career Resources

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Career Growth Profile

Arvind Salian

Age: 41

Job Title: Automotive New Production Introduction PE Manager

Employer: Freescale Semiconductor

Graduate Programs: MBA, Arizona State University, 2006; PhD, electrical engineering, University of Michigan, 2001 ; MS, electrical engineering, University of Arkansas, 1993; BS, engineering, Karnatak University, India, 1990.

Growing up in Mumbai, India, Arvind Salian epitomized "happy go lucky." The youngest of four children in a middle-class family, Salian studied just enough to make decent grades, but he much preferred being outdoors, playing sports with the neighborhood kids. His mother and sisters were constantly on his case, making sure he did his homework.

But at age 20, everything changed. Salian suffered a serious injury while playing soccer. It left him bedridden for several months, and the former athlete had to learn how to walk again.

"The feeling of helplessness and not having achieved anything of significance in my life in spite of having been given every opportunity by my family forced me to look at things differently," he says.

Upon his recovery, Salian enrolled at the Gogte Institute of Technology at Karnatak University in India and earned his bachelor's degree in engineering. Then, at age 23, he made a solo journey to the United States to continue his pursuit of higher education. Today, with two master's degrees, a PhD, and five patents under his belt, this PE manager at Freescale Semiconductor has found success on an entirely new playing field.

In Freescale's Sensor and Actuators Solutions Division, Salian manages a 12-member product engineering team to meet new product introduction (NPI) deliverables targeted for auto markets. It's a job that requires an in-depth understanding of what makes a product commercially successful, from its design and function to its pricing and marketability.

Salian's supervisor, Mike Cheperak, puts it this way: "Automotive NPI is largely about systems on chip (SOC) and system solutions in general. As the component manufacturers add more content to our products, the value of these features must be understood not only from an applications perspective—to design, validate, and test—but also from an engineering perspective. Arvind's input and understanding of the business models have helped the marketing teams to accurately price and promote products. Additionally, his understanding of our customers' road maps and strategies has improved our ability to add value to our new products."

Salian's passion for engineering comes naturally. As a boy, he marveled at his big brother's ability to repair broken radios, and he entertained the idea of one day becoming a pilot in the air force—a childhood dream that he says "was squashed the day I got my glasses."

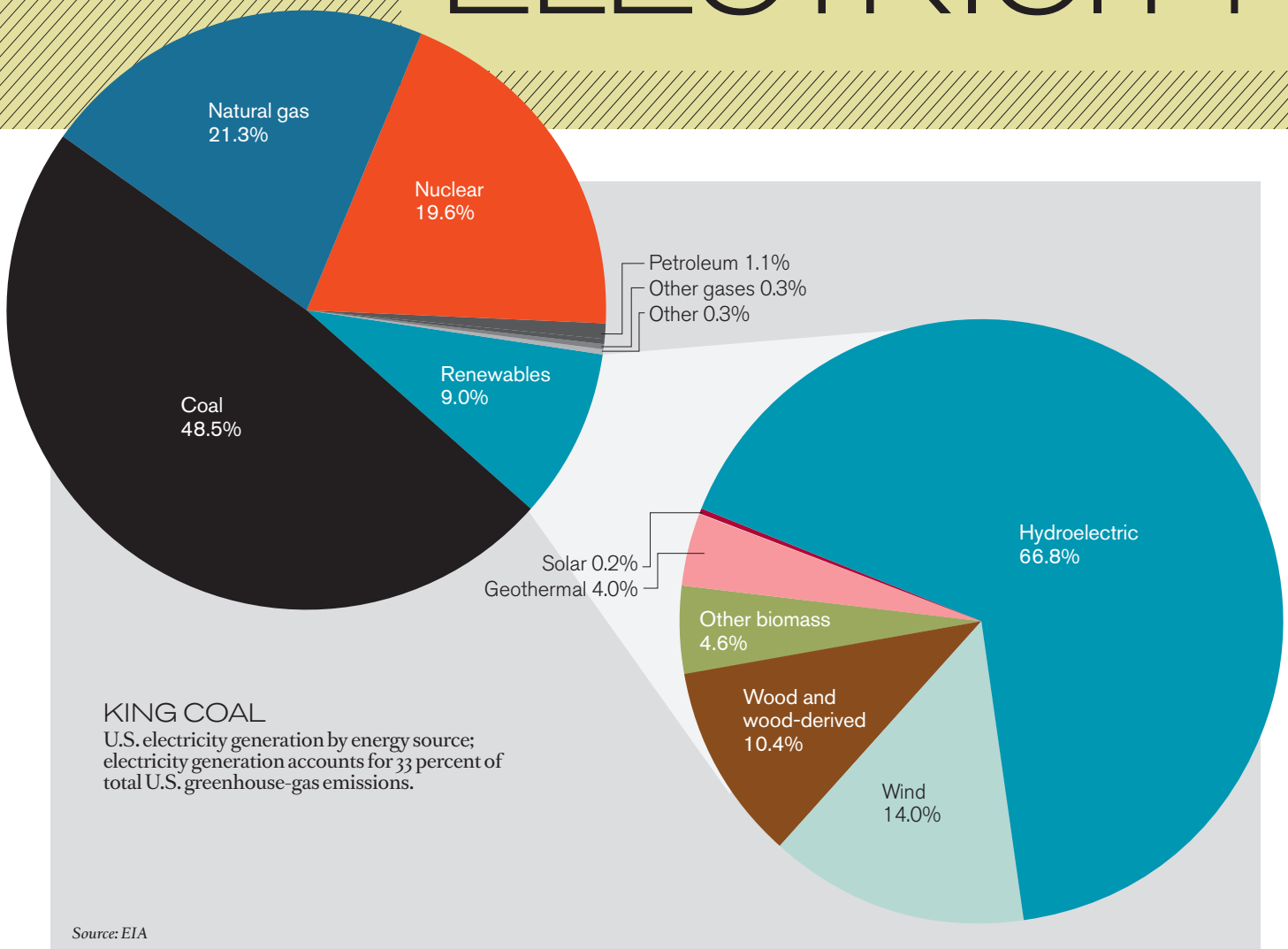
As a graduate student pursuing a master of science in electrical engineering at the University of Arkansas, Salian embraced his role as a research assistant, designing, fabricating, and testing microprobes, sensors, and microaccelerometers.

"This was an exciting experience that opened up a whole new world for me, and I wanted to learn more," says Salian; he went on to earn his doctorate in electrical engineering at the University of Michigan in 2001.

To learn more about Arvind's success at Freescale and his decision to continue his education, go to **www.technologyreview.com/careerresources/.**

Program Directory

BRIEFING ELECTRICITY



KING COAL
U.S. electricity generation by energy source; electricity generation accounts for 33 percent of total U.S. greenhouse-gas emissions.

Source: EIA

Can Renewables Become More than a Sideshow?

The great electrification projects of the 19th and 20th centuries created a world where (at least in developed countries) electricity is as common as clean water. They also created a world addicted to fossil fuels. Globally, over 40 percent of electricity is generated from coal and another 20 percent from natural gas, releasing billions of tons of carbon dioxide into the atmosphere each year.

The consensus that carbon dioxide is changing the climate in dangerous ways has convinced most politicians, scientists, and industrialists that we must reduce our reliance on fossil fuels. The U.S. Congress is currently considering a bill that calls for a 17 percent reduction in carbon dioxide emissions below 2005 levels by 2020.

But renewable power represents only about 9 percent of U.S. electricity generation. Solar

DATA SHOT

59%

The proportion of Americans who support nuclear power, according to a March poll conducted by Gallup. This level of support has remained mostly unchanged over the last 15 years.

power is responsible for a scant 0.02 percent. The reality is that renewable power and other alternatives to fossil fuels, including nuclear, remain too expensive to compete with coal and natural gas. Coal costs about two to four cents per kilowatt-hour; electricity from photovoltaics costs about five times that. Even with legislative efforts to increase the cost of emitting carbon, for the foreseeable future the imposed cost of emissions will probably to be too low to drive substantial investment in alternatives. Compounding the problem, the worldwide credit crisis that began last fall effectively halted construction of new types of power plants, many of which cost hundreds of millions to build.

Renewables are unlikely to end our reliance on fossil fuels within the next 20 years. But that is no reason for inaction. Smarter policy decisions and technological innovation can reduce what our energy sources contribute to climate change. Legislation that puts a price on carbon emissions is essential, but it must be based on a full accounting of environmental and economic costs. It is also critical that government and industry make a long-term commitment to funding energy research. The goals are clear: a smarter grid that can handle intermittent power sources and distribute and store electricity more efficiently; a realistic and safe approach to carbon sequestration; and lower-cost photovoltaics that could finally fulfill the immense potential of solar power. —*Stephen Cass*

For updates to this Briefing, take a snapshot of this code with your smart phone (for instructions, see p. 25) or visit **technologyreview.com/briefing.**

TECHNOLOGY OVERVIEW

Intelligent Electricity

The popular impression of the U.S. electricity grid, often promoted by politicians and industry, is that it is maxed out, constantly on the verge of overload. In fact, the system is grossly oversized, built to handle extreme power demands that occur for only a few hours on the hottest days of the year. In New York City, peak demand is about 35,000 megawatts of electricity. Most of the time, the city's demand is about 9,000 megawatts less—equivalent to the output of about nine nuclear power plants. To cope with minute-by-minute changes in electricity supply and demand, grid operators must maintain large reserves of generation and transmission capacity.

Reducing the need for these reserves will mean that fewer power plants have to be built to keep up with increases in demand for electricity, saving $100 billion in construction costs and curbing future greenhouse-gas emissions. Emissions can also be reduced by replacing fossil-fuel plants with zero-emission technologies, such as solar and wind farms.

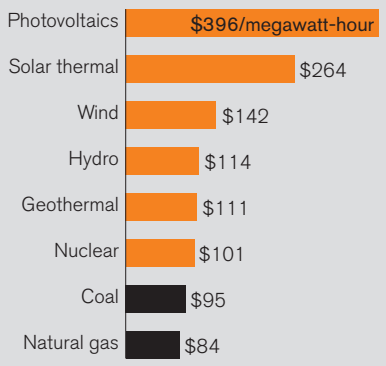
In the United States, achieving these goals will require tackling an antiquated transmission system. Half of the grid is more than 40 years old. Most of the grid is operated manually and without any real-time knowledge of what's going on in the field. If one of the aging transformers fails, the local utility may not even know until a customer calls to complain. Such slow responses have already led to cascading power failures, such as one that blacked out 45 million people in the northeastern United States in 2003.

The solution is to construct a network of sensors and controls that will give a detailed picture of the state of the grid in real time and allow rapid reactions to variations in electricity supply and demand—a so-called smart grid. These innovations will reduce the amount of excess capacity that grid operators require and make it easier to integrate renewable sources of energy. [

Sensors on transmission lines will determine how much power the lines can carry, something that varies with temperature. (For now, operators rely on conservative estimates that squander grid capacity.) Monitors installed on transformers will warn operators of problems before they occur, avoiding costly breakdowns and outages. Automated controls on transmission and distribution systems will maintain the grid's stability, even after intermittent sources such as wind and solar have begun making large contributions. In the part of the grid dedicated to long-distance transmission, most mechanical controls have already been replaced

THE PRICE OF POWER

Estimated cost of new generating technologies in 2016 *(in 2007 dollars)*



Source: Institute for Energy Research

CHARTS BY TOMMY MCCALL

 "Until the consumer sees the wholesale price of electricity, things like solar energy will not make it in the marketplace" —Cree

by digital ones that can be operated remotely—a significant step toward a smart grid. All the same, more can be done to speed up response times and further improve sensing.

A handful of demonstration projects are under way to modernize local distribution networks and extend the reach of the smart grid into homes and businesses, helping to smooth demand. Utilities already work with many industrial customers to curtail energy use during times of peak demand. With smart residential power meters, utilities can alert customers as electricity prices rise and fall with demand. Going a step further, automated appliances could respond to price signals from the meter by turning themselves off or switching to low-power mode. If, for example, 250,000 smart clothes dryers were installed in a city, during periods of peak demand, they would offset the output of an entire coal-burning power plant.

Eventually, these technologies could manage the load that plug-in hybrid and electric vehicles place on the grid when they charge. And the smart grid could make it easier for people who install solar panels and micro wind turbines to get paid for the power produced. "Over the long term," says David Mooney, director of the Electricity, Resources, and Building Systems Integration Center at the National Renewable Energy Laboratory in Golden, CO, "it's cheaper to put in microprocessors than transformers and power lines." *—Kevin Bullis*

DATA SHOT

35%

The increase in the future supply of domestic natural gas over previous estimates, according to a June report from the industry-supported Potential Gas Committee. Natural gas produces 43 percent less carbon per watt than coal, so turning to this energy source may allow electric utilities to meet emission restrictions without investing in renewable technologies.

OVER THE HORIZON

Solar Power Will Make a Difference—Eventually

Of the various next-generation technologies that are considered whenever the future of energy is discussed, cheap solar power is the most promising. Earth is bathed in nearly limitless energy from the sun, and this energy can be used to produce electricity without releasing any greenhouse gases. The European Commission calculates that fitting the surface of every south-facing roof in Europe with solar cells would completely meet the continent's electricity demands.

But the principal technologies for generating solar electricity—solar thermal power and photovoltaic cells—are too expensive to displace fossil fuels to any significant degree. Today, power produced by silicon-based photovoltaics is about five times as costly as that generated from fossil fuels. And while solar thermal systems can produce electricity more cheaply, they require large plots of land in very sunny locations.

Photovoltaics *have* been getting cheaper: according to the U.S. National Renewable Energy Laboratory, the cost of manufacturing photovoltaic modules dropped an average of 5.5 percent per year between 1992 and 2005. But even if this trend continues indefinitely, the European Commission has estimated, photovoltaics will be responsible for just 4 percent of the world's electricity by 2030. That's a con-

The largest photovoltaic plant in the United States is at Nellis Air Force Base, near Las Vegas. More than 70,00 modules produce up to 14 megawatts of electrical power.

MASTER SGT. ROBERT VALENCA/U.S. AIR FORCE

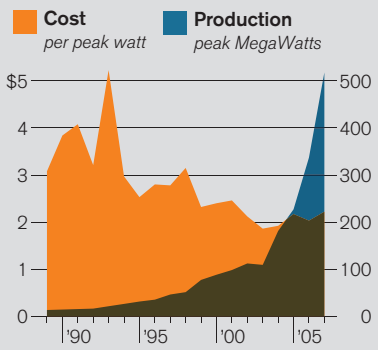
Edwards, CEO of eMeter, on the value of smart meters

siderable improvement over the tiny fraction of 1 percent of global electricity that solar power produces today, but it's still not enough to reduce greenhouse-gas emissions significantly.

What's really needed is better solar technology. Many research groups have sprung up to pursue different approaches *(see "Research to Watch," p. 101)*, which include making solar cells out of organic polymers, harnessing solar energy to split water into oxygen and hydrogen, using biological pathways and nano devices to capture solar energy in the form of liquid fuels, and trapping and harvesting photons with the aid of nanoparticles. If we develop adequate storage technologies, cheap solar power could become ubiquitous. Covering 1.7 percent of the United States' land area with solar collectors operating at an efficiency of 10 percent would supply three terawatts of power, enough to meet America's energy needs, according to Nate Lewis, a chemist at Caltech. (For comparison, 3.6 percent of the land area of the United States is in the National Park System.) In fact, the sun delivers more energy to Earth in one hour than humanity consumes over the course of a year, making solar the only renewable energy source that can keep up with global demands. —*Stephen Cass*

SOLAR RAMPS UP

Shipments made by U.S. photovoltaic companies



Source: EIA

At the Sleipner gas field in the North Sea, carbon dioxide is sequestered in a rock formation a kilometer beneath the sea floor.

INDUSTRY CHALLENGES

Coping with CO_2

Accounting for inflation, average electricity prices have held steady over the last 50 years. On the positive side, this has made electricity an engine of economic growth around the world. On the negative side, demand for inexpensive power has steadily increased, reaching 18 trillion kilowatt-hours in 2006. New, cleaner forms of power must produce electricity for between two and four cents per watt if they are to compete with coal and natural gas.

Cap-and-trade and carbon-tax proposals would make alternative energy sources more competitive by raising the cost of coal-generated electricity. But current proposals, including provisions in the American Clean Energy and Security Act being considered by the U.S. Senate, set too low a price on carbon emissions to negate the cost advantages of fossil fuels *(see "Clean-Energy Bill Will Have Little Impact," next page)*. Coal and natural gas will dominate electricity generation for the foreseeable future. Worldwide, coal plants were responsible for 41 percent of electricity generation and about 25 percent of total carbon dioxide emissions in 2006—more than 7.5 billion tons for the year. Natural-gas plants provided 20 percent of global energy, for about 1.6 billion tons of carbon dioxide. According to the U.S. Energy Information Administration, by 2020 the amount of electricity produced by coal and natural gas will increase by 40 and 60 percent, respectively.

Dealing with carbon emissions is thus the biggest challenge facing the electricity industry. It is vital to demonstrate large-scale techniques for capturing carbon dioxide emissions from coal and natural-gas plants and storing the pollutants underground. Many studies suggest that geological for-

DATA SHOT

15.7%

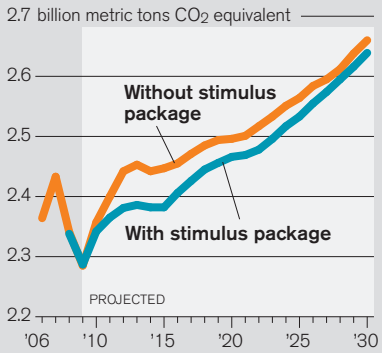
The portion of electricity generated from renewable sources in the European Union. The U.S. is not expected to approach this level until 2030. Most of Europe's growth in renewable electricity comes from wind power and plants that burn biomass, such as wood and other plant material.

DAG MYRESTRAND / STATOILHYDRO

 "In order to get significant deployment, you need four significant technological breakthroughs. ... If you need four miracles, that's

CARBON CRISIS

Carbon dioxide emissions from electricity generation in the U.S.



Source: EIA

mations can store hundreds or thousands of gigatons of carbon—decades' worth of emissions. But questions remain. Is it possible to pump carbon dioxide into the reservoirs fast enough to keep up with power production? What if the formations fracture and the gases pour back into the atmosphere? Who owns the reservoirs? Who's responsible for leaks?

Perhaps most pressing: can billions of tons of carbon dioxide be captured and stored economically? The Belfer Center for Science and International Affairs at Harvard University estimates that handling each ton of carbon will cost between $100 and $150 for first-generation carbon-capture plants, with costs dropping to $30 to $50 a ton for later plants.

Nuclear power is also an inevitable part of the future if targets for greenhouse-gas emissions are to be met. Like fossil fuels and unlike intermittent renewable power sources such as wind and solar, nuclear can provide the steady, on-demand supply of base-load electricity needed to keep the grid running. Nuclear power accounted for 19 percent of electricity generated in the United States and 14 percent worldwide in 2006, and experts expect nuclear generation to grow by 26 percent worldwide by 2020. But nuclear faces plenty of challenges, such as local opposition to new plants and the difficulty of developing a long-term strategy for handling radioactive waste. It also can't compete with fossil fuels on price. Building a nuclear plant costs roughly $107 per megawatt-hour, compared with $84 per megawatt-hour for a natural-gas plant.

Although both fossil fuels and nuclear power are bound to play major roles in the nation's energy future, federal investment in these critical technologies has been lacking. "We are just not moving with enough urgency on developing carbon-capture and sequestration technology," says Steven Specker, president and CEO of the Electric Power Research Institute in Palo Alto, CA. What's more, he warns, we've let nuclear manufacturing capacity "deteriorate" and must start thinking about rebuilding it now. "By 2020," he says, "it will be too late."—*Kevin Bullis*

POLICY

Clean-Energy Bill Will Have Little Impact

The proposed American Clean Energy and Security Act, currently being debated in Congress, calls for a 17 percent reduction in carbon dioxide emissions below 2005 levels by 2020 and an 83 percent reduction by 2050. But even though the bill provides $75 billion in direct loans and other financial support for clean-energy projects, it is unlikely to spur much new investment in renewable energy in the near term.

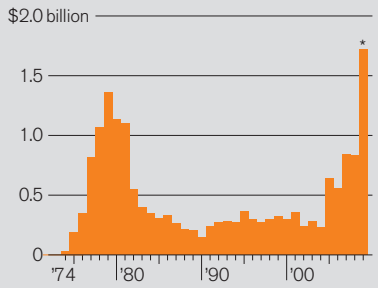
An earlier draft of the legislation required that 25 percent of the electricity produced by most U.S. utilities come from renewables by 2025. The version of the bill that the House passed in June is far less ambitious. Fewer utilities are affected, and they must meet 20 percent of demand with a combination of renewable sources and efficiency improvements by 2020. States can petition to let utilities get up to 40 percent of the way to this target through energy efficiency.

The U.S. Environmental Protection Agency estimates that when these and other potential loopholes are factored in, the portion of electricity that must come from renewables by 2020 might actually fall as low as 8 or 9 percent. Considering that 27 states and the District of Columbia now mandate much greater use of renewables, the result is a bill that "will have no substantial impact on driving renewable-energy demand until, at the very earliest, 2015 or 2016," says Ethan Zindler of the research group New Energy Finance.

The most controversial part of the bill is a cap-and-trade scheme designed to put a price on carbon emissions. A ceiling will be set on emissions, and emissions rights will be allocated to manufacturers and utilities. The ceiling, or "cap," will be lowered over

FICKLE FUNDING

Federal funding for renewable-energy research *(in 2005 U.S. dollars)*



**2009 funding includes stimulus bill*
Source: J.J. Dooley, "U.S. Federal Investments in Energy R&D: 1961-2008," Joint Global Change Research Institute, Pacific Northwest National Laboratory, October 2008; Department of Energy

unlikely: saints only need three miracles." —Stephen Chu, U.S. secretary of energy, on hydrogen fuel cells

time, making allowances scarcer and more valuable. The allowances can be traded, theoretically motivating companies to invest in renewables; those that do so won't need all their allowances and can profit by selling the excess. Under the House bill, however, the program will begin by giving away more than 80 percent of the allowances, many to coal-burning utilities. That minimizes the incentive for swift investment in zero-carbon energy.

The EPA projects that the scheme will price carbon at $13 per ton by 2015 and $16 by 2020. "Those prices are not going to be high enough to [provide an incentive to] deploy renewables," says Tom Vinson, director of federal regulatory affairs for the American Wind Energy Association. Instead, he says, it will be cheaper for utilities to manage their carbon emissions by converting from coal-generated power to cleaner fossil fuels like natural gas.

Similar problems have afflicted the European Union's cap-and-trade scheme, which has failed to demonstrate any significant impact on emissions. With carbon prices below 20 euros a ton, the scheme has produced little additional investment in renewable energy since it was introduced in 2005.

At press time, lobbyists on all sides were focusing on the Senate, which seemed to be even less inclined toward a strong energy bill than the House. One promising sign: a revenue-neutral carbon tax, the proceeds of which would return to taxpayers through payroll-tax deductions, was gaining possible favor as an alternative to the flawed cap-and-trade scheme. *—Susan Arterian Chang*

DATA SHOT

$100.7 million

The 2010 budget's cut in spending to the U.S. Department of Energy's research program for hydrogen fuel cells. The $68 million remaining on the program's budget line must now be shared with other types of fuel-cell research—but Congress may yet intervene and restore funding.

AFRICA

Giving Up on Grids

In Kenya, one million households use car batteries as their main source of electricity. From Lagos to Nairobi, even the poorest slum dwellers are driven to purchase fuel that can create power to charge cell-phone batteries and provide light. In all, more than half of Africans south of the Sahara—500 million people—aren't connected to a national electricity grid and probably never will be. In some countries, such as Malawi and Congo, fewer than 10 percent of the people are connected to the national grid. Yet the demand is there: the World Bank estimates that Africans spend $40 billion a year on off-grid power.

Lacking the billions of dollars necessary to expand creaky national electricity grids and build large power plants, Africa's political and economic leaders are experimenting with alternatives. Electricity is increasingly being generated by micro-dams, solar cells, and microturbines. "Off-grid electricity could be the next great technological leap forward in Africa," says Mark Hankins, a consultant in Nairobi who specializes in alternative power supplies.

Ericsson, the telecom company, is partnering with Orange Group, an African cell-phone provider, to build a thousand solar-powered base stations across the continent this year. Nokia Siemens is also working on new base stations; it predicts that within two years, off-grid stations will become the standard in cell-phone-happy Africa.

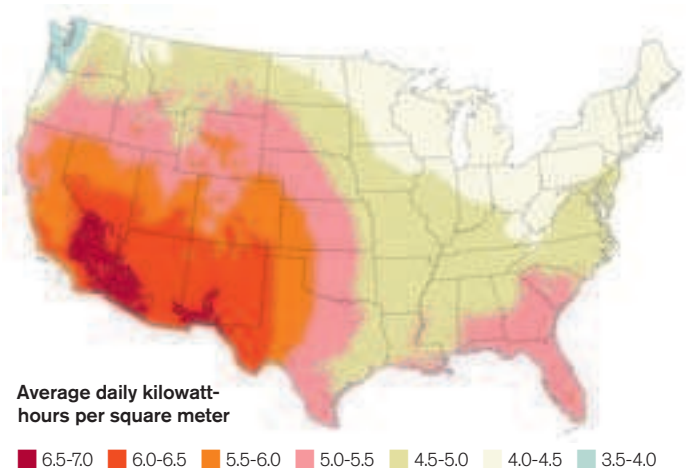
Many electricity advocates now accept that traditional national grids can never serve all or even most Africans. In an indication of this changing mind-set, last year the World Bank, which typically funds large infrastructure projects, formed a coalition, with a budget of about $12 million, to fund dozens of new products and services based on off-grid electricity. *—G. Pascal Zachary*

At this well in Mauritania, water is brought to the surface using a solar-powered pump.

PALLAVA BAGLA/CORBIS

"We don't need a breakthrough ... we can very clearly see how to halve the cost from where we are today. And that is sufficient to

SOLAR



Average daily kilowatt-hours per square meter

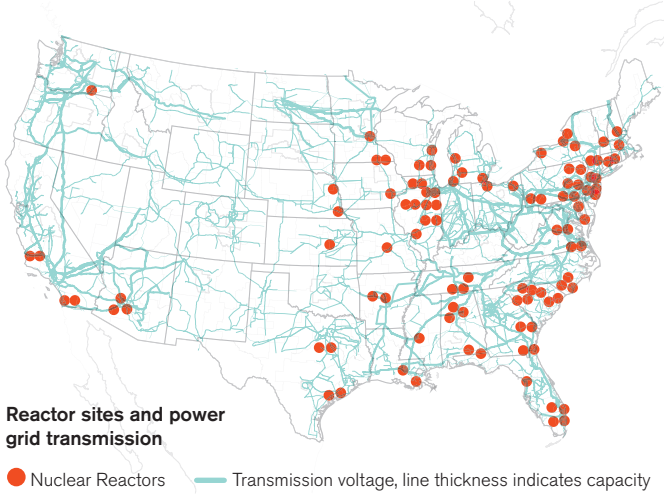
6.5-7.0 6.0-6.5 5.5-6.0 5.0-5.5 4.5-5.0 4.0-4.5 3.5-4.0

WIND

Wind power potential (at 50 meters)

Superb Outstanding Excellent Good Fair

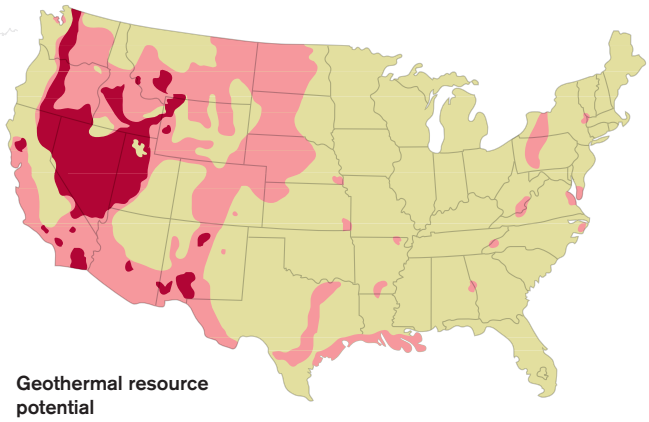
NUCLEAR POWER AND THE GRID



Reactor sites and power grid transmission

Nuclear Reactors — Transmission voltage, line thickness indicates capacity

GEOTHERMAL



Geothermal resource potential

Electric power and direct use Direct Use Heat pumps (entire U.S.)

Sources: NREL and American Electric Power.

MAPS

The Energy Belts

These maps show how the renewable resources of wind, geothermal, and solar energy are distributed across the United States, along with the locations of existing and proposed nuclear reactors. To transport electricity from renewable-rich areas to other parts of the country (particularly the East and West Coasts), groups such as the Center for American Progress, a Washington-based think tank, have proposed a new national network of high-capacity transmission lines. While the need for expanded local and regional transmission lines is clear, the argument for an overhauled national network is less so. Building such a system would be expensive, and the money may be more effectively spent in local improvements such as smart meters *(see "Intelligent Electricity", p. 92).*

fuel explosive industry growth." —Richard Swanson, founder of SunPower, on the future of photovoltaics

MARKETWATCH

Venture Capitalists Struggle with Renewables

The credit crisis that began last fall has stalled the growth of the renewable-power industry, with companies scaling back or abandoning plans for new plants, many of which were expected to cost hundreds of millions of dollar to build. But the U.S. government's promise of $6 billion in loan guarantees in the stimulus bill, plus a July release of $3 billion in grants for renewable energy, should help unfreeze projects, say Judy Chang, an economist at the Brattle Group, a consulting firm based in Cambridge, MA.

Besides established energy companies looking to enter or expand their position in the market, the biggest investors in clean-energy projects are private-equity investors, who were responsible for about $13 billion of global investment annually in 2007 and 2008.

Even in good times, however, these firms are wary of investing in previously untried technology. Solar-power companies seeking funding for utility-scale plants have been particularly hard hit. A solar plant that can produce 100 megawatts of power costs $350 million to $450 million to build, says Ethan Zindler, head of North American research at New Energy Finance, a research group headquartered in London. Such an investment is well beyond the budget of most venture capitalists, and these days, private-equity investors are reluctant to participate in such risky investments.

Venture capital investment, which plays a vital role in the initial funding of new technologies, has also retreated. In the United States, VCs invested only $154 million in clean tech in the first quarter of 2009, according to the National Venture Capital Association (NVCA)—the lowest quarterly total in four years. The average in 2008 was $1 billion a quarter. "The largest cause was uncertainty about how long the recession was going to last," says Dennis R. Costello, managing director of Braemar Energy Ventures, a VC firm with offices in Boston and New York. A long recession means that companies already on a VC's books will need more capital just to keep going, he says.

Signs of improvement have appeared in some areas of renewable energy. The NNVCA reports that VCs invested $274 million in clean tech in the second quarter. Much of the money went to electric vehicles, with Silicon Valley car manufacturer Tesla Motors picking up nearly $3 million. Meanwhile, interest in energy efficiency and smart-grid technologies has helped venture-backed companies such as Silicon Valley startup Silver Spring Networks, which is developing networking technology for utilities. Silver Spring Networks recently joined a consortium working on a $200 million smart-grid project in Miami *(see "Research to Watch," page 101)*. Startups like this one, however, will face competition from established companies ranging from meter maker Itron to IBM and Cisco.

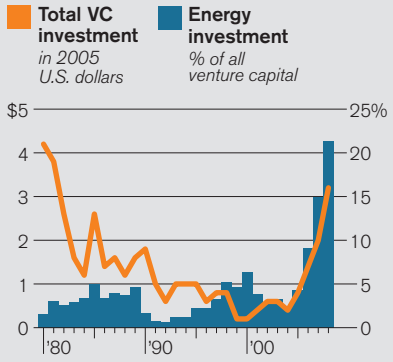
Solar power also continues to draw interest from venture investors, garnering 34 percent of clean-technology venture capital in the United States, the European Union, and Israel in the first quarter of 2009, according to Greentech Media of Cambridge, MA. Observers also say that venture capitalists are looking at opportunities in geothermal power and waste-to-power technologies. According to the NVCA, big winners in the second quarter included Ausra, a Silicon Valley solar-power company that won $25.5 million in funding, and New York City–based OwnEnergy, which focuses on wind-power projects and received $20 million.

How venture-backed startups will fare in the energy business over the long term is uncertain, however. Some believe that the high capital costs and conservative business mentality associated with the industry will favor larger companies. Renewable energy, Costello predicts, "will become a big-company game."

—Michael Fitzgerald

BACK IN FASHION?

Venture capital investments in the industrial/energy sector



Source: J.J. Dooley, "Trends in U.S. Venture Capital Investments Related to Energy: 1980-2007," Joint Global Change Research Institute, Pacific Northwest National Laboratory, October 2008

DATA SHOT

60,000

metric tons

The amount of spent nuclear fuel awaiting geological disposal by the U.S. government. The only planned repository, Yucca Mountain, was scrapped earlier this year by the Obama administration.

 "The safety of long-term storage and the efficacy of it has yet to be demonstrated on the colossal amounts we are looking at."

MARKET TABLES

Companies to Watch

PRIVATE COMPANIES

Company	Funding Raised/Sources	
Nanosolar nanosolar.com Year founded: 2002	$401.5 million Benchmark Capital, Mohr Davidow Ventures, EDF, AES	Although thin-film solar cells are far less efficient than traditional silicon cells, they could be a lot cheaper to make. Nanosolar has developed an ink made from nanoparticles that allows solar panels to be printed on metal foil by the roll. Its factory in California and a panel assembly facility near Berlin are expected to begin large-scale production later this year.
Tendril tendrilinc.com Year founded: 2004	$50 million VantagePoint Venture Partners, Good Energies, RRE Ventures, Vista Ventures, Appian Ventures	Smart-grid technology is designed to give utilities and customers real-time information about energy usage; utilities can use this information to respond more effectively to variations in supply and demand. Tendril makes outlets and thermostats that allow appliances and heating and cooling systems to be controlled through a Web interface. For example, air conditioners could be turned off during times of peak demand.
1366 Technologies 1366tech.com Year founded: 2007	$12.4 million North Bridge Venture Partners, Polaris Venture Partners	Hopes to combine a number of incremental design and manufacturing innovations in multicrystalline-silicon solar cells, with a goal of making solar competitive with coal by 2012. The company's first advance was a grooved ribbon that reflects more light onto the surface of the cell, improving efficiency by 2 percent. The company has also modified the cell's architecture to improve efficiency even further while keeping production costs constant.
Deepwater Wind dwwind.com Year founded: 2005	Undisclosed D.E. Shaw	Is trying to move wind turbines further offshore, using "jacket" support structures from the oil and gas drilling industry that are less costly than steel foundations. The company hopes to have America's first offshore wind farm running off Rhode Island by 2012.
Solyndra solyndra.com Year founded: 2005	More than $600 million U.S. Venture Partners, Redpoint Ventures, Virgin Green Fund	Hopes to corner the rooftop-photovoltaic market with panels composed of rows of cylindrical thin-film solar cells. These can absorb sunlight from all angles and are cheaper to install than conventional flat panels. The company has a U.S. Department of Energy loan guarantee for half a billion dollars, which will be used to build a manufacturing facility to churn out enough solar panels each year to generate 500 megawatts.
A123 a123systems.com Year founded: 2001	More than $250 million GE, Alliance Capital, Motorola, Qualcomm, North Bridge Venture Partners, Sequoia Capital, CMEA Ventures	A leader in developing and manufacturing lithium-ion batteries for use in electric vehicles, the company also produces multimegawatt battery units used to stabilize the electrical grid and store energy produced during off-peak hours for use when demand spikes.
BrightSource Energy brightsourceenergy.com Year founded: 2006	More than $160 million VantagePoint Venture Partners, Morgan Stanley, Black River, Google, Draper Fisher Jurvetson, BP, DBL Investors	Has contracts to supply 2.6 gigawatts of electricity to utilities using its solar thermal technology. Each solar plant will use tens of thousands of mirrors to concentrate the sun's rays on a central tower to boil water that will generate steam to turn a turbine. A 410-megawatt facility in Ivanpah, CA, the company's first, is expected to be in operation by 2012, with other farms in development throughout the Southwest.
Silver Spring Networks silverspringnetworks.com Year founded: 2002	Undisclosed Foundation Capital, Kleiner Perkins Caufield and Byers	Makes network equipment for consumer smart-grid technologies, such as smart meters, that are easier for utilities to incorporate. Its system communicates wirelessly, using standard Internet protocols.
AltaRock altarockenergy.com Year founded: 2007	$30 million Google, Khosla Ventures, Kleiner Perkins Caufield and Byers	Is trying to create new sites for geothermal plants by fracturing the hot, dry bedrock present everywhere underneath the earth's surface and then feeding cold water into the fractures to retrieve the heat. The technique can create small earthquakes, however; a DOE safety study could derail the company's demonstration project in Northern California.
Stirling Energy Systems stirlingenergy.com Year founded: 1996	$100 million NTR	Uses large, mirrored parabolic dishes to concentrate light driving a stirling engine located at the dish's focus. The engine converts thermal energy directly to mechanical energy to turn a generator. The company has contracts to produce nearly a gigawatt of power for the California grid in the coming years.

–Ralph Cicerone, president of the National Academy of Sciences, on carbon sequestration

PUBLIC COMPANIES

Company	Installed or Owned Generating Capacity	
General Electric ge.com Market cap: $122.73 billion	Unavailable	Its energy division has businesses in nuclear reactors, fossil fuels, renewables, fuel cells, energy storage, grid systems, and energy-efficient smart appliances. One of the world's biggest suppliers of wind turbines, the company plans to spend $1.5 billion a year on clean-energy research by 2010.
Xcel Energy xcelenergy.com Market cap: $8.53 billion	16.4 gigawatts	This Minneapolis-based utility supplies power to eight states in the Midwest and Southwest. Most of the electricity Xcel generates comes from its dozens of coal and natural-gas plants, though customers can pay a premium for electricity from its wind farms. The company is investing in a city-scale smart-grid project in Boulder, CO.
Exelon exeloncorp.com Market cap: $33.68 billion	33 gigawatts	The largest U.S. electric utility, providing 20 percent of America's nuclear power. Has proposed a 10-megawatt solar array on the South Side of Chicago, to be funded by the loan guarantee program in the federal stimulus package; it would be the nation's largest urban solar plant.
SunPower us.sunpowercorp.com Market cap: $2.02 billion	400 megawatts	Claims to make the most efficient flat-panel solar technology commercially available, using cells that convert 22 percent of sunlight into electricity. Last year it won a contract to provide panels for what will be the largest photovoltaic installation in the world, a 250-megawatt plant in Northern California that's set to start generating electricity next year. The recent drop in demand for solar panels has forced the company to scale back its production and delay completion of a new factory in Malaysia.
Ormat Technologies ormat.com Market cap: $1.75 billion	1.2 gigawatts	Has installed more than 10 percent of the world's geothermal capacity, with plants in the United States, Central America, Africa, and New Zealand.
Abengoa Solar abengoasolar.com Market cap: $2.29 billion	22.6 megawatts	Headquartered in Spain, Abengoa pursues a variety of solar thermal and photovoltaic technologies. The company has signed an agreement with an Arizona utility to build a 280-megawatt plant near Phoenix. One version of its solar thermal technology uses mirrors to concentrate the sun's energy onto a central receiving tower. Abengoa also has over 11 megawatts of photovoltaic capacity in operation.
Vestas vestas.com Market cap: $14.9 billion	33 gigawatts	The world's largest manufacturer of wind turbines, Vestas currently controls 20 percent of the global market.
First Solar firstsolar.com Market cap: $12.39 billion	1 gigawatt	Recently pushed the manufacturing costs of its cadmium telluride thin-film solar panels below $1 per watt. Has delivered more than a gigawatt of solar generation capacity to date. Although the vast majority of First Solar's customers are in Europe, last year the company completed a 10-megawatt plant in Nevada. It's currently the largest thin-film installation in the country, and First Solar recently signed an agreement to expand it to 58 megawatts if the operating utility can find a buyer for the electricity.
BP Solar bp.com Market cap: $160.91 billion	1 gigawatt	Has been manufacturing silicon solar cells and panels for longer than three decades. In the face of the economic downturn and increasing competition from competitors, the company recently closed down photovoltaic manufacturing facilities in Spain and Australia, and it's phasing out panel assembly at its plant in Frederick, MD.
Duke Energy duke-energy.com Market cap: $18.87 billion	35 gigawatts	Generates most of its electricity from coal, natural gas, and oil. In 2007, the company received permission from Indiana regulators to build the world's first large-scale Integrated Gasification Combined Cycle plant, which converts coal into a cleaner burning gas. Also operates a large fleet of nuclear reactors in the Carolinas and has submitted an application for a license to build a new two-reactor facility in South Carolina.

 "I don't think there is an understanding of the scale of the task that lies ahead. This will be a long transformation, and it is

MARKET TABLES

Research to Watch

Project/Principal Institutions	
Energy Storage Systems Research Program www.sandia.gov/ess Sandia National Laboratory	Is investigating ultracapacitors and flywheels, along with zinc-bromine, sodium-sulfur, vanadium redox flow, and lead-acid batteries, to more efficiently store electricity on the grid.
Energy Smart Miami www.energysmartmiami.com General Electric, City of Miami, Cisco Systems, Silver Spring Networks, Florida Power and Light	A two-year, $200 million smart-grid project, rolling out a million smart meters to consumers.
Upwind www.upwind.eu A consortium of 40 European universities and businesses, led by the Technical University of Denmark	Is developing the components need for large wind turbines, each able to generate 8 to 10 megawatts; also investigating new materials for rotor blades and improving generator designs.
Large-Scale Wind Generation Analysis wpweb2.tepper.cmu.edu/ceic/research.asp Carnegie Mellon Electricity Industry Center	Is studying how the grid can cope with the intermittent nature of wind power as it becomes responsible for a bigger portion of generated electricity.
FutureGen www.futuregenalliance.org The U.S. Department of Energy and the FutureGen Alliance, an international consortium of large coal users and producers	Hopes to begin constructing the first near-zero-emissions coal plant next year, at a cost of $1.5 billion. Generating 275 megawatts, it will demonstrate carbon capture and sequestration.
CERTS Microgrid project certs.lbl.gov/ University of Wisconsin, American Electric Power, and the Consortium for Electric Reliability Technology Solutions	Microgrids will make it easier to integrate distributed energy resources, such as microturbines and residential photovoltaics, into utility-scale grids.
Cooper Basin Power Plant www.uq.edu.au/geothermal/our-challenge University of Queensland Geothermal Energy Center of Excellence, Australia	Is supporting the development of an Australian geothermal plant that could supply four gigawatts of electricity by 2030, which would make it the largest such power plant in the world.
Gen IV Nuclear Reactors www.gen-4.org Argonne National Laboratory, Generation IV International Forum	Is developing a number of designs for advanced fission reactors, with the goal of creating cheaper and safer reactors that produce less waste. Commercial reactors based on the designs could follow in about 20 years.
Helios helios.lbl.gov Lawrence Berkeley National Laboratory, UC Berkeley	Is trying to use solar energy to produce fuels through a variety of approaches, including synthetic biology and the development of new materials.
Powering the Planet Center for Chemical Innovation www.ccisolar.caltech.edu/ A consortium of universities and energy companies centered at Caltech	Is developing advanced materials that can be combined to split water into oxygen and hydrogen using sunlight.

going to be very expensive." —Richard Lester, director of MIT's Industrial Performance Center, on federal research funding

REVIEWS

WINE

In Vino Veritas

WINEMAKERS DISAPPOINTED BY ORGANIC METHODS HAVE TURNED TO BIODYNAMICS AS THE PUREST ROUTE TO WINE THAT'S TRUE TO SOIL, GRAPE, AND CLIMATE.

By CORBY KUMMER

For years the question in winemaking was how technology could make wine better. This was especially true if the wine was Californian. When California cabernet sauvignon bested the best of Bordeaux—in a legendary blind tasting, the "Judgment of Paris," convened by the English wine merchant Steven Spurrier—it was a moment of great national pride at the time of America's Bicentennial, and it was achieved in part because California winemakers had used technology in ways tradition-bound French winemakers would not. As California wine became respectable, Silicon Valley millionaires bought vineyards in Napa and Sonoma counties. California wine and tech soon enjoyed a happy marriage.

BENZIGER ESTATE V.2006 TRIBUTE
Sonoma Mountain
14.5% alcohol
$80.00
www.benziger.com

Two generations of winemakers came out of the University of California at Davis armed with the latest knowledge of clones, viticulture, and gas chromatography. With their chemical toolbox, they could fix any flaw—a dry year, overripe grapes left on the vine a day or two too long, sour wine. The descendants of the original Hungarian and Italian immigrants who first planted grapes in Napa and Sonoma may have been slow to sign on to the new methods, but not the high-tech grandees who were living the California dream by buying land and putting their names on bottles of wine. New money is always attracted to old vineyards (even if California's vineyards aren't really that old).

Like most activities the very rich are drawn to, winemaking is highly subject to fashions. The current fashion is a practice that was far on the fringes even 10 years ago: biodynamic farming, ever so much more authentic and true to nature than plain old organic. It's the realization of what an increasingly vocal minority of winemakers, particularly in France, began calling for in the 1980s—utterly unmanipulated wines, with no corrections, no adjustments, no filtering, and no chance to compensate for a mistake made during the growing season.

That true reflection of the air, rain, sun, and soil of a place is what's meant by *terroir*, the cachet-laden term being slapped on every local food these days. Biodynamic farming, says the studiedly eccentric, preternaturally persuasive California winemaker Randall Grahm, "is the royal road to *terroir*."

This approach sounds completely in tune with Slow Food, the movement (about which I wrote a book) that since the 1980s has called for a return to growing and production methods dictated by nature, place, and subsistence economics. These are the methods that gave rise to the world's great artisan foods and wines in the centuries before *artisan* was needed to indicate "non-industrial," when organic was the default.

Biodynamic principles in fact predate organic farming, although both were reactions to the rise of nitrogen-laced fertilizers in the early 20th century. In 1924, the Austrian-born philosopher Rudolf Steiner gave a series of lectures on farming as it related to anthroposophy, the movement he founded upon Goethe's scientific works. Anthroposophy attempts to unite science, the arts, and the spiritual and invariably views the part in the context of the whole, up to and including the cosmos. It survives in applied "daughter forms" that include the Waldorf schools—and biodynamic farming.

Steiner's followers argue that Sir Albert Howard, the British botanist who pioneered organic agriculture after observing Indian farming practices, Lord Northbourne, the agronomist who coined the term *organic farming* in his 1940 book *Look to the Land*, and the publisher J. I. Rodale, who popularized it in the United States, were simply building on and codifying his ideas. As organic farming is now defined in government standards, however, the important things are what you *don't* do: apply chemical pesticides and fertilizers to crops and soil. But farmers can draw on a whole range of nonchemical surrogates for the chemical correctives they give up. It takes three years to gain full organic certification, as the land detoxes, and then it's relatively straightforward.

INSECTARIES are natural habitats for beneficial insects that control pests. The Benziger Family Winery's main insectary is planted with more than 50 kinds of plants and flowers.

COURTESY OF BENZIGER FAMILY WINERY

Biodynamic, though—that's really hard. Steiner, who gave his lectures on the home farm of a count who had an estate in what is now Poland, viewed farms as living, unified organisms that should be completely self-sustaining. Maintaining that standard means paying daily attention to exactly what's happening in your vineyard and your dirt. It means not buying the pest fighters and fertilizers that still get delivered every season to organic farms. It means constantly rebuilding soil for the future. It means not planting a good portion of your land at all—and if you're in Sonoma or Napa, that's some of the most expensive farmland on earth—and raising cows, sheep, goats, chickens, and the other animals that keep a farm thriving and independent.

A biodynamic label can differentiate a wine from the passel that are already organic. But the term hasn't quite reached the point of conferring bragging rights. Also standing in the way of status is the hippie image. Biodynamic farming involves using sprayed applications meant to encourage growth and keep pests in check, composts infused with various herbs in homeopathic quantities, and a bunch of shamanistic, ridiculous-sounding "preparations" based on a too-literal reading of what Steiner, observing life on Central European farms, mentioned in his few writings on farming.

The Benziger Family Winery, in Glen Ellen, is a postcard-perfect biodynamic farm, and the people who run it speak with the air of calm longtime converts—unlike several winemakers I talked to on a recent visit to Sonoma and Napa, who were slightly scary. When it comes to hearing about some biodynamic practices—burying manure in a cow horn in autumn and digging it up in spring; burying oak bark in a goat's skull; using stags' bladders and cows' intestines as casings for herbs; planting and picking on "root, leaf, flower, and fruit days" shown on lunar farming calendars covered with zodiac symbols—it can be hard to tell the difference between calm and zealotry.

Glen Ellen is a relic of an era when a family of normal means could buy a beautiful piece of land and grow grapes. Mike and Mary Benziger bought the property in 1980 with the help of Mike's father, Bruno, a wine and spirits importer. Bruno and his wife moved there a year later, and other siblings followed. It was "quite mediocre" wine, Mike Benziger says, that made them change their farming ways: "We'd killed what would have been native yeasts"—the naturally occurring organisms long beloved of sourdough-bread bakers and now of winemakers—"through years of using herbicides, so we had to add lab yeasts." The soil was "very like dirt balls or talc," and was strangely quiet: "You just heard the wind in the vines. It was a green desert." Now, Mike says, the soil is "almost cakelike—like brownies."

The view as Mike talks, from a hillside vineyard across to another hill, is a patchwork of zinfandel vines, lavender, rosemary, and olive trees. Demeter, the international certification program for biodynamic farming (it has branches in 43 countries), requires that 10 percent of a farm's land be uncultivated—not as much as the percentage that would have to be wild, or reserved for grazing, in a truly self-sufficient farm, but enough to scare off farmers who profit from a single crop, however much they dislike monocropping.

Although many biodynamic vineyards do not have enough cows to make all the manure they need (and are thus not the truly closed system that is the biodynamic ideal), the Benzigers' three cows are sufficient to their needs. They also raise sheep that clean fields by eating weeds, and grow vegetables that renew soil by providing cover crops—and provide beautiful purslane, lamb's-quarter lettuce, and fresh peas to be sold to Ubuntu, an organic vegetarian restaurant in downtown Napa that is the talk of the food world. And this being a postcard, the farmer who delivers those vegetables is a photogenic straw-hatted college grad married to a former cook at Chez Panisse (and who, by complete chance, tested recipes for my book on Slow Food).

The Benzigers are quick to point out that they use satellite imagery and sophisticated soil analysis and winemaking technology to verify their low-tech methods. The high-tech–low-tech seesaw they boast about—and also the high-tech money that finances low-tech methods all through Sonoma and Napa—is on equally scenic display at DaVero, a farm just outside Healdsburg, the Napafying but not completely Napafied main town of Sonoma County. DaVero is kept alive by the money its owner, Ridgely Evers, made developing QuickBooks software. Its chief product is olive oil, and it leaves much more than the required 10 percent of its land open—60 percent, Evers claims.

Evers gives at least one compelling reason for paying to be certified as biodynamic rather than organic: it's good marketing. Biodynamics can fulfill the promise that organics make but don't fulfill: as Evers succinctly summarizes it, food that's "sustainably and responsibly farmed near where you live." That, indeed, is the idea that started Slow Food in the 1980s and made it into an international movement in the '90s, and that made *locavore* the *New Oxford American Dictionary*'s 2007 word of the year. And it's the promise that got buried in the years leading up to the USDA's National Organic Program (NOP), which finally set a single national standard for organic certification after years of state-by-state definitions. "They didn't codify best practices," Evers says, in an undiplomatic summary of what many farmers think of the USDA's approach. "Lobbying organizations came in, and now the NOP is so far from what people think *organic* means as to be a joke."

COW HORNS are filled with manure and buried through the winter to create biodynamic preparation 500, which promotes root growth.

Many of the vineyard owners and farmers I talked to called biodynamic the new organic. And unlike early organic-farming associations, Demeter is taking no chances that the standards it's using will be watered down. It has registered a trademark in the United States on the word *biodynamic* itself. Now its work will be to make consumers understand the meaning of biodynamic farming and its stricter-than-organic rules.

Interest in biodynamic farming is growing, chiefly among winemakers. Disillusion with big industry's encroachment on organics and desire for a marketing edge have led Demeter's U.S. membership to triple in the past five years, according to Elizabeth Candelario, Demeter USA's marketing director.

One reason winemakers are more drawn to the biodynamic label than the organic is that they outright reject organic winemaking methods (though not organic farming methods). "The organic law in the U.S. is not sustainable for winemaking," says Larry Stone, a legendary sommelier who is now pursuing his boyhood dream of winemaking as the general manager of the very successful Napa winery Rubicon, owned by Francis Ford Coppola. The problem, he explains, is that the standards for organic wine were written at the same time that high sulfite levels in salad bars were causing health problems. So the permitted levels of sulfites in wine—10 parts per million—are much lower than the European standard of about 50 parts per million. Good news for migraine sufferers who think sulfites are triggers. Bad news for red-wine makers: "It's almost impossible to make wines, especially red wines, that can withstand the ravages of oxidation after a year," Stone says. Thus the great disparity between the number of organic vineyards and the number of organic wines. Biodynamic standards for sulfites are in line with European ones for organic wine—which gives Demeter a big market opportunity.

But is it even possible to tell that a wine is biodynamic? In particular, does biodynamic wine taste any better?

You won't find reason to suppose so in the winemaking itself. Biodynamic certifiers dictate no loony methods for making wine, though the calendar for propitious times to make it—those leaf and fruit days—strikes many winemakers as superstitious. The winemaker's skill, or lack of it, determines the taste of any wine. And so, of course, does the quality of the vineyard.

But the argument that biodynamic farming produces better-tasting grapes is easy to make and easier to test. Chefs including Jeremy Fox, at Ubuntu, say that biodynamically grown fruits and vegetables are more likely than organic ones to taste of themselves—that elusively pure and focused flavor cooks always pursue. When Jim Fetzer, part of a family that has adopted the slogan "The Earth-Friendly Wine," converted its

COURTESY OF BENZIGER FAMILY WINERY

160 acres to biodynamic practices to sell grapes to the Fetzer winery (now owned by a conglomerate), Benziger and others called them the most beautiful grapes they'd ever seen.

The wines Benziger makes from grapes grown in its own biodynamic vineyards are highly regarded—particularly the Benziger Estate Sonoma Mountain V.2006 Tribute, a cabernet blend the winery introduced five years ago as a "tribute" to biodynamic farming. It has a surprisingly shy nose for a wine that, as is the California custom, is a high 14.5 percent alcohol. It is delicate on the palate, too, because it includes cabernet franc, merlot, and petit verdot, and far cleaner and less oaky than the California norm. Tribute is deceptively luscious; it's so clean in the nose and light on the tongue that only after a while does the deep fruit creep up on you and make you want more, much more—very unlike the usual brassy, heavy, overripe California cab. It's not cheap (about $80 in retail stores), but the French style will appeal even to timid merlot drinkers. Is Tribute so good because of the sympathetic family's beautiful property and admirable farming methods? Maybe. It's certainly because they know how to make wine.

Many grape growers in both valleys are sold. David Bos, a young farmer with midwestern roots and the evangelical air of the religion major he once was, extols the advantages of biodynamics; all five of the vineyards owned by Grgich Hills, the Napa winery he works for, are Demeter-certified. "People ask if it makes economic sense," he said when he took me to one, near Yountville in Napa. (Several farmers said their initial changeover to biodynamics cost them a few thousand dollars an acre over several years.) "But we've seen biodynamics heal our vineyards." Using biodynamic methods, he rescued a blighted vineyard other growers would have torn up. Now, grapes from that vineyard are part of his esteemed Yountville cab. "We've been making 300 to 400 cases a year," he says. "We sell it only through our tasting room, and it sells out at $135 a bottle."

Vintage '70s farmers move quickly from the realm of the practical to the spiritual. Michael Sipiora, for instance, farms at Quintessa, a spectacular property on the Silverado Trail. He knows wine; he farmed the vineyards at Stag's Leap before joining the conservation-minded couple who own Quintessa, Valeria and Agustin Huneeus. The difference between organic and biodynamic, he told me, lies in "energy." He went on to talk about Steiner's levels of consciousness: the "etheric" level of plant life, the "astral" level of the animal kingdom, the cosmic and telluric levels of energy we share with animals, the "eagle" level attained by humans.

Sipiora buries crystals and "puts intent" on them. Water—"the great messenger"—is his main theme. His pride is the "flow form," a cascading fountain with double bowls on each level that spins water in opposite "vortexes," charging it with energy; he pipes that water around the property. He makes many of Steiner's preparations himself—valerian, stinging nettle, and chamomile are basic components—and what he can't grow on the property, he buys from the Josephine Porter Institute in Virginia: stag's bladder, oak bark for burying in skulls.

This kind of cultishness drives Aaron Pott crazy. Pott is a winemaker and consultant (formerly for Quintessa) who is planting his own vineyard. He studied at both UC Davis and the University of Burgundy and worked at two chateaux in Bordeaux, so he is familiar with New World and Old. He first encountered biodynamic farming in France and learned more when Quintessa expanded its biodynamic program. He calls many biodynamic preparations "ludicrous" and "medieval."

The problem, he says, is that Steiner wrote little on grapes (just half a page in his agricultural lectures), and his knowledge of farming was based on his experiences in chilly Central Europe—entirely removed from the climate of Napa and Sonoma. Many of the preparations aim to encourage ripening of grapes, whereas in California, overripening is the concern.

Pott doesn't dismiss biodynamics altogether. "The tenets I like," he says, "are those things that say—the way Steiner actually said—'Look at everything that's around you. Use preparations that work. These are things that work for me in the middle of Germany.' You see what's naturally occurring on your farm and use those techniques." Pott crushed leaves of the agave plant, whose interior stays moist in the desert, and sprayed them on vines to prevent sunburn—and "lo and behold, it worked." Why don't others adapt Steiner's philosophy to such pragmatic effect, and discard what is clearly unsuitable to their own climate? He shrugs. "Why don't Christians follow the teachings of Christ?"

In the end, it comes down to faith. Scientific studies comparing organic and conventional farms have shown that organic farms have better soil quality, according to John Reganold, a soil scientist at Washington State University. But studies comparing the soil on biodynamic and organic farms show "mixed results," he says. He has compared soil from adjacent biodynamic and organic vineyards and seen no difference; and although a chemical analysis of grapes revealed some differences, in a blind tasting of merlot wines from those vineyards, wine tasters were stumped. Still, Reganold is an advocate: "Biodynamic farmers observe and are in contact with the crop more often than conventional growers." And, of course, he likes that biodynamic farmers care so much about the soil.

If *biodynamic* means only that the soil the grapes were grown in will be better for generations to come, that's all right. "There's no money in winemaking, let me tell you," says Jim Fetzer, whose family stayed in property development and grape growing after selling its winery. The money is in the land. Given the undisputed benefits biodynamic farming has for the life of soil, maybe it's a good investment after all. TR

CORBY KUMMER IS A SENIOR EDITOR AT THE *ATLANTIC* AND THE AUTHOR OF *THE JOY OF COFFEE* AND *THE PLEASURES OF SLOW FOOD*.

NETWORKING

Entangled Light, Quantum Money

A BREAKTHROUGH EXPLORES THE CHALLENGES—AND SUGGESTS THE FINANCIAL POSSIBILITIES—OF CREATING QUANTUM NETWORKS.

By MARK WILLIAMS

In recent years, the Austrian physicist Anton Zeilinger has bounced entangled photons off orbiting satellites and made 60-atom fullerene molecules exist in quantum superposition—essentially, as a smear of all their possible positions and energy states across local space-time. Now he hopes to try the same stunt with bacteria hundreds of times larger. Meanwhile, Hans Mooij of the Delft University of Technology, with Seth Lloyd, who directs MIT's Center for Extreme Quantum Information Theory, has created quantum states (which occur when particles or systems of particles are superpositioned) on scales far above the quantum level by constructing a superconducting loop, visible to the human eye, that carries a supercurrent whose electrons run simultaneously clockwise and counterclockwise, thereby serving as a quantum computing circuit.

"FUNCTIONAL QUANTUM NODES FOR ENTANGLEMENT DISTRIBUTION OVER SCALABLE QUANTUM NETWORKS"
Chin-Wen Chou, Julien Laurat, Hui Deng, Kyung Soo Choi, Hugues de Riedmatten, Daniel Felinto, and H. Jeff Kimble
Science 316: 1316–1320 (2007)

"MAPPING PHOTONIC ENTANGLEMENT INTO AND OUT OF A QUANTUM MEMORY"
K. S. Choi, H. Deng, J. Laurat, and H. J. Kimble
Nature 452: 67–71 (2008).

The physicist Richard Feynman proposed the idea of quantum computing in 1981 to exploit the information-processing potential of atoms, photons, and elementary particles. By now, the field has advanced sufficiently far that researchers not only are able to manipulate physics for unprecedented experimental effects but have proposed commercial applications.

But before technologies like quantum communications, computing, and metrology can realize their potential—a quantum Internet and uncounterfeitable money are two interesting possibilities—quantum networks must be able to transmit and store data. The quantum optics group at the California Institute of Technology has been working toward this goal. The team is headed by H. Jeff Kimble, Valentine Professor of Physics, who led the 1998 effort that achieved the first unambiguous teleportation of one photon's quantum state—that is, the information represented by its spin, energy, and such—to another photon. Now Kimble and his team have demonstrated a way for entanglement—the nonlocal relationship that allows quantum teleportation, which Einstein skeptically dismissed as "spooky action at a distance"—to be created in networks.

Much as the motion of electrons in microprocessor circuits transmits data within today's computers, the teleportation of quantum states between entangled particles would perform that task in quantum networks. As for data storage, says Kyung Soo Choi, a researcher in Kimble's group, a central question that one of their recent experiments resolved was, "How do you convert entangled light into an entanglement of matter and back into light?" Entangled states are fragile, and networks of entangled light will require repeating devices—much the way long-distance fiber-optic networks require optoelectronic repeating devices to regenerate diminishing signals. Therefore, entanglement will need to be generated and stored in component subsystems within a greater quantum network. Now Kimble and his team have demonstrated a technical solution to the problem.

The Caltech team used two ensembles of cesium atoms whose states they influenced with a laser, making them either transparent or opaque as needed to manipulate incoming photons' speeds. The researchers then split single photons, putting them in superposition—that is, they were part of the same quantum wave function and, thus, entangled—while ensuring that they propagated along two paths into the two cesium ensembles. Choi explains, "We slowed the light to a crawl and halted it inside the matter by deactivating the control laser that was making the cesium ensembles transparent, so the quantum information—the entangled light—was stored inside the atomic ensembles. By reactivating the control laser, we reaccelerated the photons to normal speed, restoring the beams of entangled light." So far, the Caltech researchers have stored entanglement in matter for spans of one microsecond. Kimble estimates that he and his team can extend that to 10 microseconds.

Kimble possesses a courtly Texas gentleman's manner, as I discovered after his lab manager found him 15 minutes on the schedule following two weeks when the physicist was away, making presentations at four conferences on two continents. Those 15 minutes became a tutorial on recent technical advances in verifying and quantifying entanglement. Measurement is the central problem in quantum mechanics, since any particle or system exists in a quantum state only until another system, whether one as slight as a stray air molecule or as complex as a human observer, gains information about it and thereby collapses that state. This is mind-bendingly abstruse stuff. Aside from discussing quantum metrology, though, Kimble made one easily graspable assertion: "Our society's technical base is information commerce. In the next 20 years, quantum information science—a fusion of computer science and quantum mechanics that didn't exist 20 years ago—will radically change that commerce."

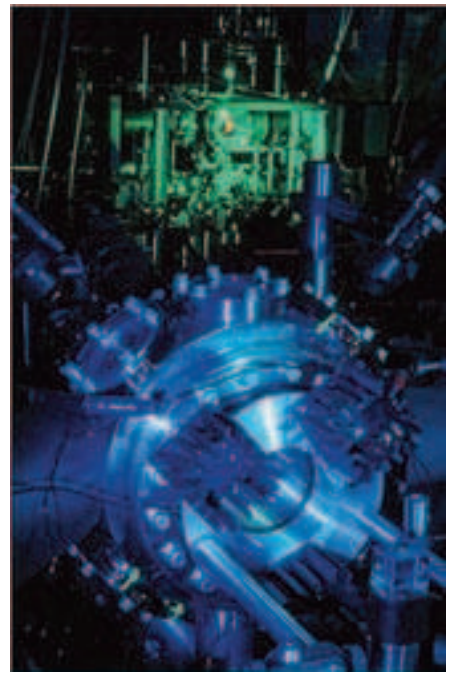
The revolutionary technology that Kimble envisions is large quantum networks, resembling the Internet but relying on entangle-

ment. What inherent advantages would promote the development and adoption of such networks?

Substantial ones. Quantum networks have already been built on a limited scale. In 2004, the world's first permanent quantum cryptography system was activated in Cambridge, MA, linking Harvard, Boston University, and DARPA contractor BBN Technologies (formerly known as Bolt Beranek and Newman, under which name the company created the original ARPAnet). Today, id Quantique, a Swiss company, and MagiQ Technologies, a U.S. one, offer commercial modules using optical fiber to transmit quantum keys, in the form of photons encoded as bits by controlling their polarization, over limited distances that top out at about 100 kilometers. Since attempted interception of these light particles would disturb their state and expose eavesdropping, such quantum cryptography systems offer absolute data security.

Furthermore, the prospect of quantum computing was what provided the initial impetus for research into quantum networks. If such computing can be done seriously (so far, experiments have used at most seven qubits, or quantum binary digits), it promises to surpass classical computing in significant respects. Scott Aaronson, an MIT expert on computational complexity, cites the algorithm published in 1994 by MIT mathematician Peter Shor as the breakthrough that proved quantum computing a viable proposition by demonstrating that it could factor very large numbers in reasonable computing time. Because that task has been beyond classical computers, most public-key cryptography has hitherto been based on factoring large numbers. But it would be vulnerable to cryptanalysis based on quantum computing. As Aaronson says, "That's why the National Security Agency is interested in quantum computing." Quantum cryptography, however, would offer data security against quantum code-breaking as well as against regular cryptanalysis.

Besides ensuring the security of data, the quantum wide-area repeater networks, or QWANs, that Kimble has in mind would possess few of current networks' latency issues—indeed, could be as nearly instantaneous as light speed allows. Moreover, the exponential parallelism that would give quantum computing its power—with two entangled particles, or qubits, representing four different values, four qubits 16 values, and so on—ought to apply to networks of quantum computing devices. Kimble says, "Though there'll be a largest size attainable for the state space of individual quantum processing units, it'll be possible to surpass that by linking those units together into a fully quantum network." A quantum computer's "state space" is the full range of potential states in which the computer could exist. When a quantum algorithm is run, this computational process collapses that state space and shrinks the computer's range of possible states down to a single one: the correct answer to the given problem. With a network of quantum computers, Kimble is claiming, the exponential computational power of each device would be multiplied exponentially.



TWO NODES of a quantum network that Caltech researchers created by halting entangled photons within two ensembles of cesium atoms housed in an ultrahigh-vacuum system. Temporarily storing entanglement provides a basis for quantum data storage, which might be useful for various applications, including quantum cryptography.

COURTESY OF NARA CAVALCANTI

MIT's Seth Lloyd has given some thought to the design options for quantum networks. He says, "Networks using cesium-atom ensembles are one of the most promising technologies for transporting quantum information over long distances." Yet the ensemble approach is relatively bulky, and the larger a quantum system, the greater the problems for computing. Lloyd says, "Circuit-based approaches like superconducting loops are more scalable within a small space, with potentially large numbers of qubits on one circuit board." But such systems are unsuitable for communications. "Kimble and I have collaborated on concepts using individual atoms instead of ensembles," he says. "If we could move information between atomic ensembles and individual ions and ion traps, that's a scalable quantum technology." A plausible scenario, according to Lloyd, seems to be to use ensembles for communications and the more localized, scalable quantum devices, like the superconducting loops or the ion traps, for computation.

So Kimble has a reasonable argument that quantum networks are feasible. And the advantages that he envisions—absolute data security, no latency, and a further exponential gain in computational power—would hardly be negligible in the world of information commerce.

Some commercial applications of quantum information technology are fairly obvious. Human stock traders have come to rely on the computerized trading programs known as high-frequency traders (HFTs). On some days, these generate more than half the volume on the New York Stock Exchange. Major trading institutions have

spent millions developing their algorithms to analyze market data and execute large numbers of trades according to strategies that are, mostly, sophisticated variations on buying microseconds after some data arrives and then selling microseconds later at the expense of other traders who couldn't get the data in or their trades out as rapidly. Futures traders who use near-instantaneous quantum networks will have clear advantages over those who don't.

Other commercial applications are possible as well. Scott Aaronson suggested one of them in a paper called "Quantum Copy-Protection and Quantum Money." He observed that quantum states cannot be copied because any measurement process destroys them, which "raises the possibility of using quantum states as *unclonable information*." Exploiting this possibility will require circumventing the fact that quantum states collapse under measurement and creating, first (for purposes of quantum money), unclonable states that can be verified as authentic, and second (for purposes of quantum copy protection), unclonable states that would still allow the protected software, DVDs, CDs, and so on to be used. Aaronson demonstrated that at least one type of publicly verifiable quantum money and two schemes for quantum-based copy protection are theoretically feasible—raising the possibility, for the first time ever, of absolutely uncounterfeitable money and insurmountable digital-rights protection.

The first generation of money emerged with the invention of coins in Lydia nearly 3,000 years ago, its second generation with the paper bills of exchange issued by the banks of Renaissance Italy, and its third with electronic money and the virtual economy of the modern era. If scientists like Kimble and Aaronson are correct, quantum networks may soon give rise to a further generation of money. TR

MARK WILLIAMS IS A CONTRIBUTING EDITOR TO *TECHNOLOGY REVIEW*.

COURTESY OF CASEY REAS/BITFORMS GALLERY, NYC.

PROGRAMMING

When a Good Idea Works

PURITY, OPENNESS, AND SIMPLICITY ARE ENGINES OF DESIGN.

By JOHN MAEDA

In 1995, I visited the home of the late, great designer Paul Rand, who had designed the iconic logos of IBM, ABC, and NeXT. I still vividly recall him opening a letter and chuckling while reading it: "Mr. Rand, I love your design for the CBS logo." He was laughing, of course, because the design wasn't his: it was the work of the late, great designer William Golden. But Rand was far from annoyed by the misattribution. "If you live long enough, people will think you did everything," he told me. He was in his 80s at the time.

PROCESSING
processing.org

In 2001, when I was a young MIT faculty member overseeing the Media Lab Aesthetics and Computation Group, two students came up with an idea that would become an award-winning piece of software called Processing—which I am often credited with having a hand in conceiving. Processing, a programming language and development environment that makes sophisticated animations and other graphical effects accessible to people with relatively little programming experience, is today one of the few open-source challengers to Flash graphics on the Web. The truth is that I almost stifled the nascent project's development, because I couldn't see the need it would fill. Luckily,

GORGEOUS Casey Reas uses Processing to create high-resolution photographic prints. "This image was generated by thousands of autonomous software agents carrying out their instructions," he explains. "Shapes are drawn as they intersect—the size and colors are determined by the agents' behaviors."

Ben Fry and Casey Reas absolutely ignored my opinion. And good for them: the teacher, after all, isn't always right.

Processing began with a simple idea. Fry was a gifted Carnegie Mellon grad who had a background in graphic design but could also program in Apple II assembly language. Reas was a gifted University of Cincinnati grad who had a background in graphic design and a passionate desire to understand computation; as design director at I/O 360 Digital Design in the mid-1990s, he had been one of the few classically trained graphic designers who understood the possibilities of computer programming, but he left his job (and probably a few gazillion dollars) to study computer code for real at the Media Lab. Both were accomplished artists who had exhibited at the Whitney, the Museum of Modern Art, and elsewhere. They loved working with each other, and they wanted other programmers and designers, artists and scientists, to have an easy way to share work with each other and understand each other's ideas. They wanted to give visual expression to sophisticated forms of computation, and they wanted a rich community toolkit for sharing libraries, experiences, and work in an elegant format.

The starting point for their project was something that I *can* take credit for: the Design by Numbers (DBN) framework for teaching programming to artists and designers. I originally wrote DBN in the 1990s, but I couldn't get it to yield production-quality work. My graduate student Tom White made it into something that was much more functional. And then Fry and Reas took a crack at it. DBN limited users to drawing in a 100-by-100-pixel space, and only in grayscale—faithful to my Bauhaus-style approach to computational expression. But Fry and Reas figured that people needed color. They needed canvases larger than 100 by 100. They realized that this wasn't in line with my interests, so they went off and made their own system that gave users no restrictions at all.

In one sense, Processing arose as a response to practical problems. When Java first came out, it offered minimal support for sophisticated graphics processing. Drawing a line and stuff like that was possible, of course. But it couldn't do transparency or 3-D, and you were almost guaranteed to see something different on a Windows computer and a Mac; it was incredibly cumbersome to do anything that was both sophisticated and cross-platform. So Fry, who grew up hacking low-level graphics code as a kind of hobby, built from scratch a rendering engine that could make a graphically rendered scene appear the same in a Windows or a Mac environment. It was not just any renderer—it borrowed the best elements of Postscript, OpenGL, and ideas cultivated at the MIT Media Lab in the late Muriel Cooper's Visible Language Workshop.

From the start, however, it was more than just a way to build on Java. While Fry was at work on his renderer, Reas began developing processing.org as a locus of learning and community, creating an active forum where users discuss their projects, share and solve programming problems, and offer ideas for improving Processing itself. Indeed, Processing had the spirit of an art project or a labor of love. As artists, Fry and Reas were keen to give the software as much expressive power as they could; they used it to produce work that felt like art. Soon, people wanted to emulate them. And they could. Processing was open-source and free of charge. Because Fry and Reas were doing this for no particular hope of financial gain, and because they were awfully hard-working and nice guys, its fans couldn't help loving Processing for its purity.

Since then, Processing has grown up quite a bit. Books have been published on its applications, and I see stunning Processing animations in television commercials and all over the Web. I am fairly confident that the number of people who use it is significant and growing. I doubt that it will overtake Flash, but I think it continues to give it a good run for the money. Because it is open-source, many people are extending Processing in ways that I'm sure surprise Fry and Reas. Mobile editions, JavaScript workalikes, hardware programming platforms—I'm sure we'll see it on iPhones eventually. Processing is being faithfully copied by a variety of folks so that it can run on different platforms—a testament to its popularity.

Processing, however, isn't entirely *easy*. Perhaps the only thing working against it is that it has a higher bar of entry than other visually oriented systems like Flash. Programming in general eventually gets hard; you have to embrace the mathematics at some point in the game. But there's nothing like inspiration as a motivator. Just the other day, I had an e-mail conversation with graphics guru Robert Hodgin, a graduate of the Rhode Island School of Design. At RISD, we don't have much mathematics training to speak of, and Roger left without much algorithmic know-how. But he is now extremely skilled with a sophisticated mathematical repertoire, because he has made the leap from pigments and straightedges to numbers and relational symbols. He *wanted* to learn what at first was hard. In the end, it's just work. And artists know how to work!

Processing was written and developed by two boys next door who are also visual and computational geniuses. Fry and Reas wrote it for themselves—and also for the world at large, to help everyone share in the rich vocabulary of computational expression. Processing exemplifies my core belief about education today: let the new generation do their thing and just get out of their way. Download it today, and play. TR

JOHN MAEDA IS PRESIDENT OF THE RHODE ISLAND SCHOOL OF DESIGN AND THE AUTHOR OF *THE LAWS OF SIMPLICITY.*

Meters for the Smart Grid

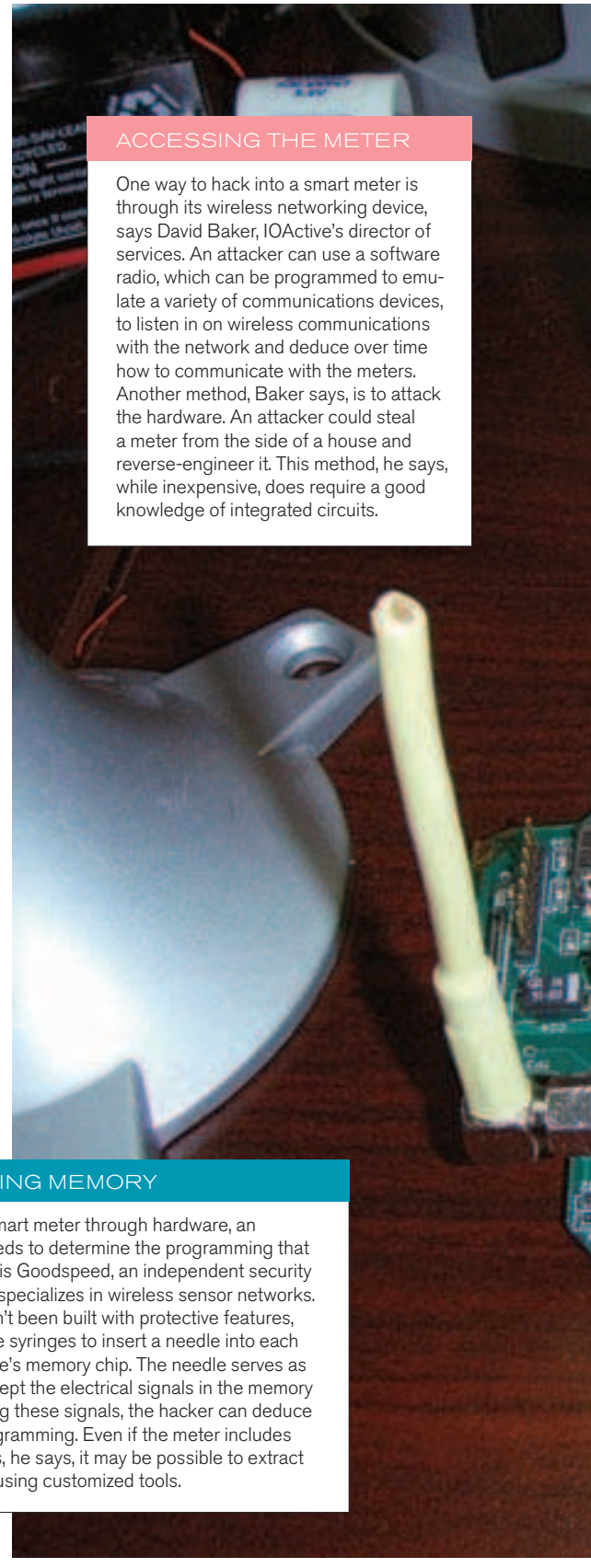
RESEARCHERS SAY NEW ENERGY INFRASTRUCTURE ISN'T NEARLY SECURE ENOUGH.

BY ERICA NAONE

IN THIS YEAR'S economic stimulus package, the United States government allocated $4.5 billion to developing technologies for the "smart grid," a revamped delivery system for electricity. Advocates envision a digital system that can make energy-saving adjustments to power flow. Several million networked meters have already been distributed in the United States.

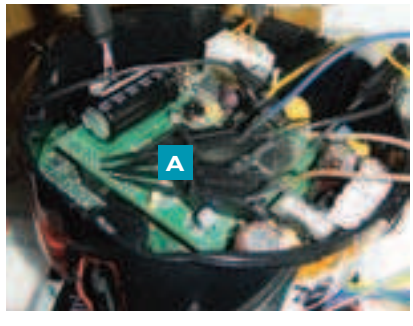
But critics say that rushing to roll out this system could give rise to security problems. At a recent conference, Mike Davis, a senior security consultant at the Seattle-based research company IOActive, gave a presentation on a proof-of-concept cyber attack that could potentially allow an attacker to shut off large numbers of meters remotely. Researchers say now is the time to test the smart grid and get security right.

The current generation of smart meters, Davis says, "is probably not mature enough" for some of the new network features. He has not publicly released brand names of meters he has tested. This page shows a sample smart-meter interior.



ACCESSING THE METER

One way to hack into a smart meter is through its wireless networking device, says David Baker, IOActive's director of services. An attacker can use a software radio, which can be programmed to emulate a variety of communications devices, to listen in on wireless communications with the network and deduce over time how to communicate with the meters. Another method, Baker says, is to attack the hardware. An attacker could steal a meter from the side of a house and reverse-engineer it. This method, he says, while inexpensive, does require a good knowledge of integrated circuits.



A ATTACKING MEMORY

To hack into a smart meter through hardware, an attacker first needs to determine the programming that runs it, says Travis Goodspeed, an independent security researcher who specializes in wireless sensor networks. If the meter hasn't been built with protective features, a hacker can use syringes to insert a needle into each side of the device's memory chip. The needle serves as a probe to intercept the electrical signals in the memory chip. By analyzing these signals, the hacker can deduce the device's programming. Even if the meter includes security features, he says, it may be possible to extract the information using customized tools.

SPREADING MALWARE TO THE NETWORK

With access to one smart meter's programming and codes, Baker says, someone can communicate with all the meters of the same brand that are connected to the network. To demonstrate his attack, Davis crafted a piece of malware that could self-replicate to other meters, allowing an attacker to shut them down remotely. In simulations, Davis showed that if his worm were released in an area where all the houses were equipped with the same brand of meter, the worm could spread to 15,000 homes in the space of 24 hours.

MEASURING ELECTRICAL USAGE

At the heart of a smart meter are the sensors that measure energy usage. Unscrupulous individuals have long tried to save money on their electric bills by interfering with a meter's ability to accurately report how much energy has been consumed. That type of fraud may still be possible on a smart meter, though many of the devices are designed to protect against the mechanical methods traditionally used.

B DIGITAL RADIO

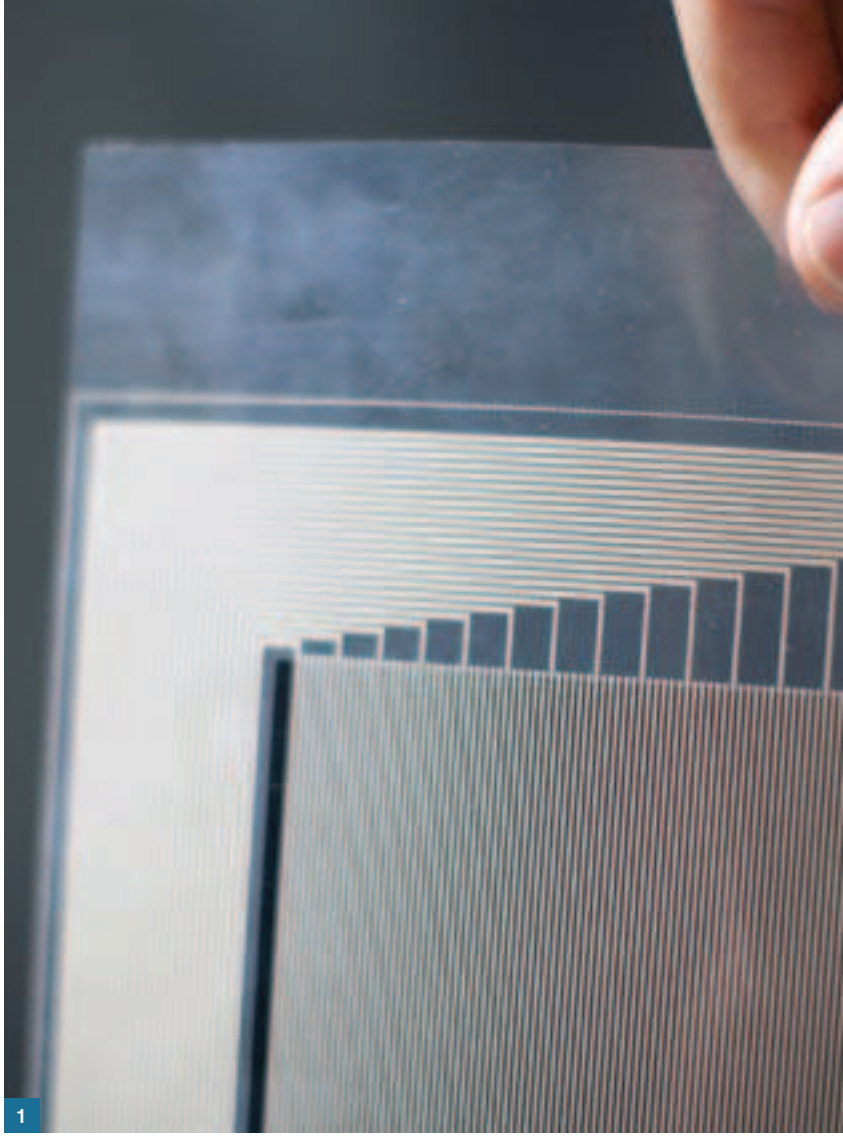
The smart meter's two-way radio chip allows the device to be read remotely and to receive commands over the network. The software in the chip contains security codes that an attacker who's cracked the meter's programming can use to get on the network and begin issuing commands. Goodspeed has shown that the codes can be extracted using syringes in a process similar to the attack on the memory.

COURTESY OF MIKE DAVIS

A Touch of Ingenuity

AN INEXPENSIVE PRESSURE-SENSITIVE PAD COULD MAKE SURFACES SMARTER.

By KATE GREENE



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PORTER GIFFORD

Now that more and more smart phones and MP3 players have touch-screen interfaces, people have grown accustomed to interacting with gadgets using only taps and swipes of their fingers. But on the 11th floor of a downtown Manhattan building, New York University researchers Ilya Rosenberg and Ken Perlin are developing an interface that goes even further. It's a thin pad that responds precisely to pressure from not only a finger but a range of objects, such as a foot, a stylus, or a drumstick. And it can sense multiple inputs at once.

The idea for the pad occurred to Rosenberg, a graduate student at NYU, a few years ago when he was working with a conductive polymer called force-sensing resistor ink, which is often used in electronic music keyboards. When pressure is applied to the ink, its molecules reorient themselves in a way that alters its electrical resistance, which is easy to measure. Rosenberg originally used the ink to create sensors that could be embedded under tennis-court boundaries to automate line calls, but he wondered if it might be the basis of a good multitouch interface for computers. He began collaborating with Perlin, a professor in NYU's Media Research Laboratory, to make a pressure-sensitive touch pad to replace a computer mouse.

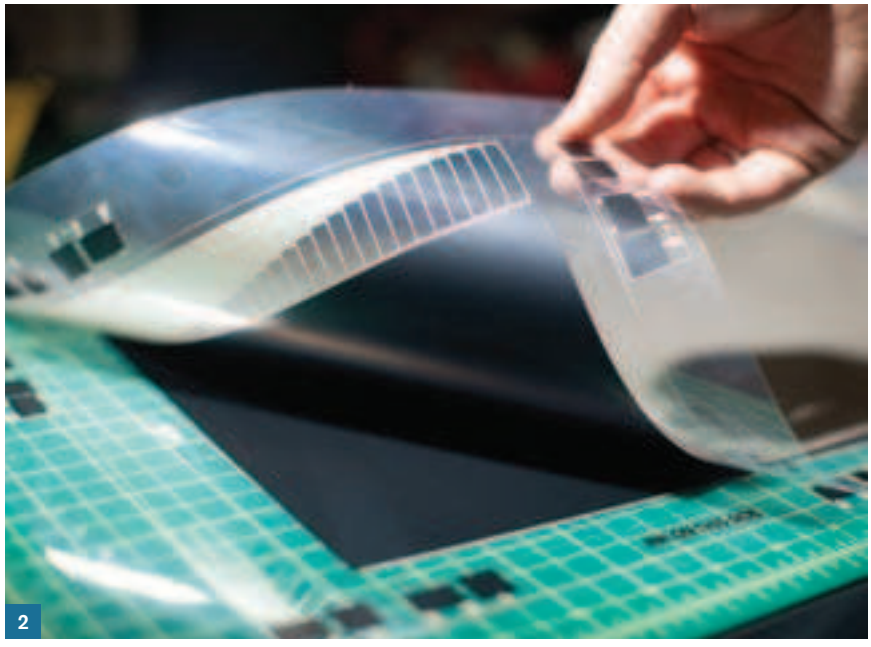
Pressure-sensitive pads have existed for years, but most have been limited to simple applications, such as sensing when a car seat is occupied. Devices like the Palm Pilot, which use a stylus to input data, typically detect touch by measuring changes in electrical resistance when an object taps the screen. But these screens can register only a single touch at a time. Touch screens on smart phones, meanwhile, use a sensor that detects changes in capacitance, or the material's ability to hold an electric charge; capacitance changes when objects containing water—including fingers—move across the screen. Such screens can sense multiple touches, but they can't detect pressure.

Rosenberg and Perlin's touch pad, by contrast, combines some advantages of all these technologies. It can simultaneously register the pressure and location of several touches, and it can be simply and inexpensively shrunk to the size of a pendant or scaled up to cover a tabletop.

PAINTED PLASTIC

To build a pressure-sensitive touch pad, Rosenberg starts with sheets of plastic slightly thicker than a piece of paper. He uses a special program to design a pattern of lines that will be printed on each sheet, tailoring the pattern to the device's intended use. The lines are laid down on the plastic in metal to make them electrically conductive; the sheet is then covered with an even coat of the black pressure-sensitive ink. In bulk, the printed sensors would cost about $100 per square meter, but since these letter-sized prototypes are one-offs, each one is about $100.

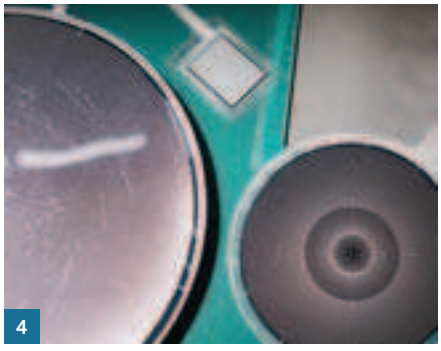
Rosenberg places two of the prepared sheets against each other with the polymer ink side facing in, orienting them so that

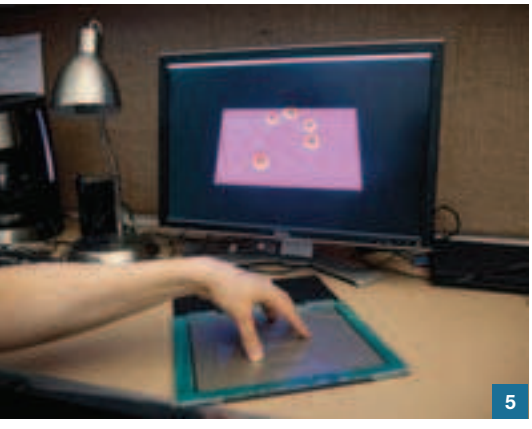


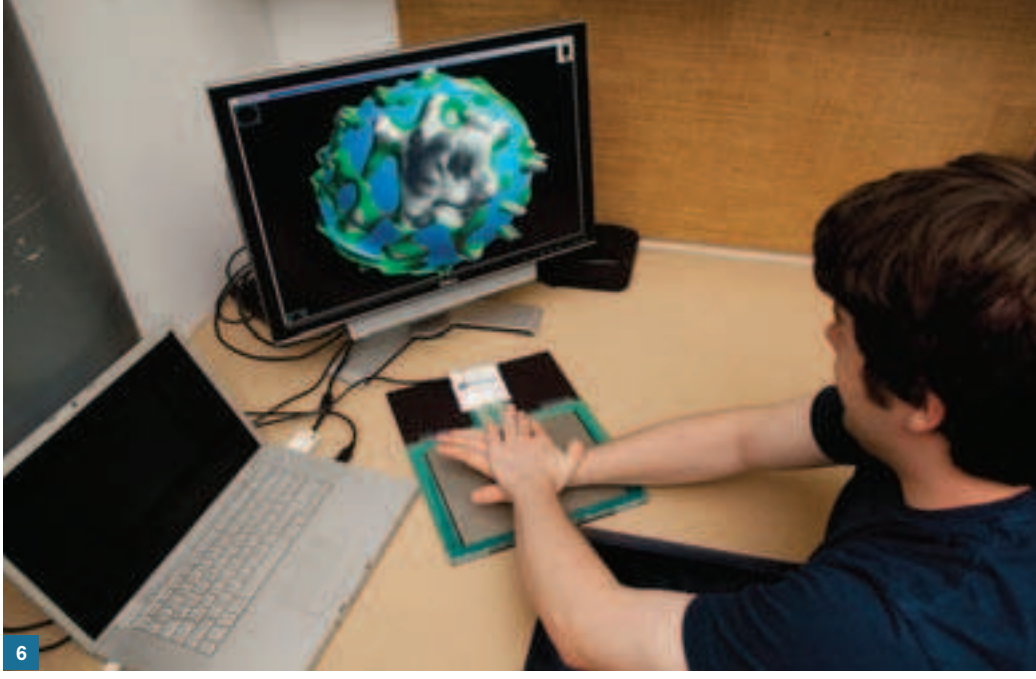
the conductive lines create a grid. Then he sticks the sheets together with double-sided tape. Every sixth metal line terminates at one edge of the plastic sheets in a short, flexible tail that is connected to a rigid circuit board by a clamp. Though the rest of the wires are not connected to electronics, they influence the electrical characteristics of the active lines, which helps software infer where a touch is coming from.

The circuit board itself contains a microchip programmed to scan the sensor pad, supplying power to each active wire in quick succession. The chip also converts the pressure data from a continuous analog signal into a digital format that a computer can interpret. Finally, it compresses the data and sends it to a computer via a USB connection or (for musical applications) a MIDI port.

Bottom left: Ken Perlin (left), a professor of computer science at NYU, and Ilya Rosenberg, an NYU graduate student, show off the plastic sheets that are the starting point for their pressure-sensitive touch pads.
1. Rosenberg holds a sheet of plastic that has been imprinted with thin lines of metal. The researchers design the patterns and send them to an electronics facility for printing.
2. A layer of pressure-sensitive black ink is applied on top of the conductive lines. Rosenberg lines up two sheets, ink side in, and sticks them together with tape to make the pad.
3. The conductive lines terminate at the edge of the pad, where they connect to a specially designed circuit board. It collects the pressure data and sends it to a computer via a USB port.







4. The plastic sheets come in many shapes and sizes: one the size of a credit card could be used for small handheld electronics, while circular pads are designed for electronic drum pads.
5. Rosenberg presses down on a completed pad with his fingers; software on the computer interprets the range of pressures that he's exerting and displays them on the screen. The intense pressure near the center of his fingertips shows up as red, while the lighter pressure around the edges is blue.
6. The team has developed several applications for the pressure-sensitive pad, including this demo program, which allows users to manipulate a globe and alter its surface by pressing down on the pad.

Software on the computer calculates both the position of objects that contact the pad and the amount of pressure they exert. If an object touches at the intersection of two conductive lines, the electronics register a strong current there; but the farther away from the intersection it touches, the weaker the current, owing to the resistivity of the ink. Prototypes already have resolution high enough to accurately sense finger and stylus input for tablet PCs. For a single touch, it can record forces from five grams to five kilograms with a 2.5 percent margin of error—enough range to interpret the light tap of a stylus or a strike on a digital drum. Perlin says that because so few of the wires need to be powered, larger versions of the pad can achieve similar sensitivity without much more complexity or cost.

MARKET PRESSURE

Today's prototypes are an opaque black, so they're unsuitable as touch-screen interfaces for cell phones and other electronic gadgets. But such a precise and inexpensive pressure-sensitive interface still has many potential uses, Perlin says.

For instance, Rosenberg and Perlin have collaborated with other researchers on several medical and scientific applications. Perlin says the pad could be added to shoes to monitor gait and to hospital beds to alert nurses when a patient has been still for too long, increasing the risk of pressure sores. The pad is even sensitive enough to measure pressure waves in water and air; this could lead to better fluid-dynamics models that might help with designing airplanes and boats. Today, researchers use arrays of individual sensors to collect such data, but they are too expensive to use over a large area.

The technology is also useful in multitouch interfaces for electronic devices. Patrick Baudisch, a researcher at the Hasso Plattner Institute in Germany, has integrated the pad onto the back of a small gaming gadget, effectively adding an ergonomic touch input: users can control the game without having their fingers block the screen. And Rosenberg believes that by using a different type of pressure-sensitive ink and making the lines thinner, he and his colleagues can build a transparent sensor usable in touch screens on mobile phones and tablet PCs.

Rosenberg and Perlin's touch pad is much more sensitive than other resistance-sensing devices, says Andy Wilson, a Microsoft researcher who developed Surface, a commercially available multitouch table. "Many of the applications focus on using the pressure sensor in interesting ways," he says. He adds, however, that the technology is still in its early stages, and it's difficult to say how much cheaper it will be than today's touch interfaces.

In April, Rosenberg and Perlin launched Touchco, a startup that will license the technology and provide design assistance to companies that want to build it into devices such as mobile phones and e-readers. The company's engineers are exploring additional applications—such as the first electronic hand drum, which would be impossible without a sensor capable of such fine resolution.

Eventually, these thin, unobtrusive touch pads could be built into virtually any surface, opening up a new dimension of multitouch interaction. TR

To see these touch pads in action take a snapshot of this code with your smart phone (for instructions, see p. 25) or visit **technologyreview.com/demo**

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FROM THE LABS

INFORMATION TECHNOLOGY

Revealing Phishers

A NEW APPROACH RELIABLY IDENTIFIES FRAUDULENT WEBSITES

SOURCE: "FIGHTING PHISHING WITH DISCRIMINATIVE KEYPOINT FEATURES"
Kuan-Ta Chen et al.
IEEE Journal of Internet Computing 13(3): 56–63

Results: Software designed by researchers at the Academia Sinica in Taiwan can recognize websites designed to trick people into revealing information such as passwords and bank-account numbers, a scam known as phishing. In tests, the system recognized these sites between 95 and 98 percent of the time.

Why it matters: It's been estimated that phishing costs Americans a billion dollars a year or more. Methods for identifying phishing sites have been developed, but existing techniques don't catch them all. The new approach promises to identify these sites more reliably.

Methods: Because phishers usually try to fool users with fake Web pages that look like genuine pages from eBay, PayPal, or some other target site, the researchers focused on a page's appearance rather than its content. Their system examines common target sites and identifies "keypoints"—points in an image that can still be recognized even if the scammer changes colors or adds distracting elements. It then compares new sites that a user visits with the pattern of keypoints on common target pages. If the patterns prove too similar, the pages are flagged as possible phishing sites.

Next steps: The researchers are developing a browser plug-in that uses their system to warn people when they may have reached a phishing site.

Fabric Camera

OPTICAL FIBERS REPLACE LENSES

SOURCE: "EXPLOITING COLLECTIVE EFFECTS OF MULTIPLE OPTO-ELECTRONIC DEVICES INTEGRATED IN A SINGLE FIBER"
Yoel Fink et al.
Nano Letters 9: 2630–2635

Results: Researchers at MIT have found a way to take photographs with polyester fibers. They integrated eight photodetectors into the fibers, arranged the fibers into a 32-by-32 grid spread over an area the size of a record album, and used the grid to capture a black-and-white image of a smiley face.

Why it matters: A standard camera requires lenses, which are rigid and fragile and can be heavy. A camera made from fibers, however, could be foldable, durable, and lightweight. In one potential application, it could be integrated into soldiers' uniforms to create images of the surrounding environment.

Methods: Lenses focus scattered light to form an image. In the absence of a lens, measurements of the intensity of the scattered light can be used to computationally derive an image. To "photograph" the smiley face, the researchers illuminated it with laser light at different wavelengths,

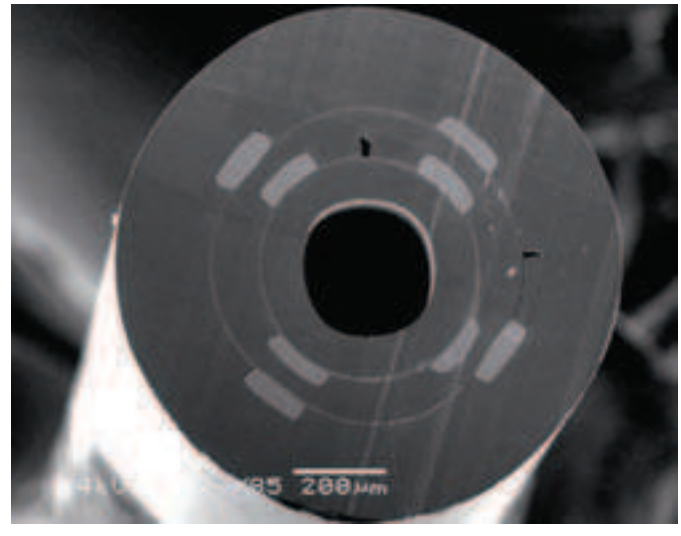


PHOTO FIBERS
Cross-sections of two polymer fibers, each less than a millimeter in diameter, show eight light sensors (gray rectangles) made of semiconducting material. The micrographs show two possible configurations for the sensors.

COURTESY OF THE FINK LAB/MIT

green and red. The photodetectors, embedded in a ring within each fiber, were able to distinguish light from each laser. After measuring the relative intensity of the colors, the researchers were able to apply algorithms that calculated the phase of the light-waves scattered by the face. A separate algorithm used the phase information to reconstruct the image.

Next steps: The researchers plan to add more sensors to the fibers so that they can make images of objects illuminated with natural light. This could also lead to a color camera.

BIOMEDICINE

Heart Repair

PATIENTS' OWN BONE MARROW CELLS HELP RELIEVE CHEST PAIN

SOURCE: "INTRAMYOCARDIAL BONE MARROW CELL INJECTION FOR CHRONIC MYOCARDIAL ISCHEMIA: A RANDOMIZED CONTROLLED TRIAL"
Jan van Ramshorst et al.
Journal of the American Medical Association 301: 1997–2004

Results: Three months after being injected with cells derived from their own bone marrow, patients with reduced blood supply to the heart muscle—a condition known as ischemic heart disease—had better blood flow to the heart, less chest pain, and better exercise capacity.

Why it matters: Previous studies testing the benefits of bone marrow cells on different types of heart disease have shown mixed results. This study is the first to show an improvement in blood flow, and it suggests that this type of cell therapy may be more effective in people with chronic heart conditions, such as angina, than in those who have suffered heart attacks.

Methods: Scientists extracted 80 milliliters of bone marrow from each patient and isolated mononuclear cells—a mix of stem cells and progenitor cells. Then they injected either a solution of these cells or a placebo into the heart muscle. After three months, the scientists used magnetic resonance imaging and other methods to assess blood flow to the heart. They also measured patients' ability to exercise comfortably for a specified time and assessed their quality of life.

Next steps: The researchers are trying to determine which of the different cell types in bone marrow have the greatest benefit and how they improve blood flow—for example, by encouraging the growth of new blood vessels or improving the health of existing ones.

Glowing Monkeys

PRIMATES PASS A FLUORESCENCE GENE TO THEIR OFFSPRING

SOURCE: "GENERATION OF TRANSGENIC NON-HUMAN PRIMATES WITH GERMLINE TRANSMISSION"
Erika Sasaki, Hiroshi Suemizu, et al.
Nature 459: 523–527

Results: Scientists transferred a gene derived from jellyfish into marmoset monkeys, causing them to produce a protein that makes them glow green. The monkeys then passed the gene for the fluorescent protein to their offspring, which glow as well.

FLUORESCENT FEET
These monkeys inherited a genetic modification that makes them glow (insets) under ultraviolet light.

Why it matters: Genetically engineered mice have become common and vital tools for biomedical research. Now it's possible, for the first time, to make genetically engineered strains of primates. Scientists could use the modified animals to study neurological diseases such as Parkinson's, which cannot be adequately reproduced in rodents.

Methods: To create the transgenic monkeys, researchers injected a virus carrying the gene for green fluorescent protein, or GFP, into 91 marmoset embryos. Eighty healthy transgenic embryos were then transplanted into surrogate mothers, which gave birth to five glowing offspring. Three glowing second-generation marmosets have been born since April.

Next steps: The researchers are further refining their approach to deliver larger pieces of DNA and to block the action of specific genes. Both techniques will be necessary to develop marmoset models of human disease.

MATERIALS

Energy Storage

NANOSTRUCTURES BOOST PERFORMANCE OF LITHIUM-SULFUR BATTERIES

SOURCE: "A HIGHLY ORDERED NANOSTRUCTURED CARBON-SULFUR CATHODE FOR LITHIUM-SULFUR BATTERIES"
Linda F. Nazar et al.
Nature Materials 8: 500–506

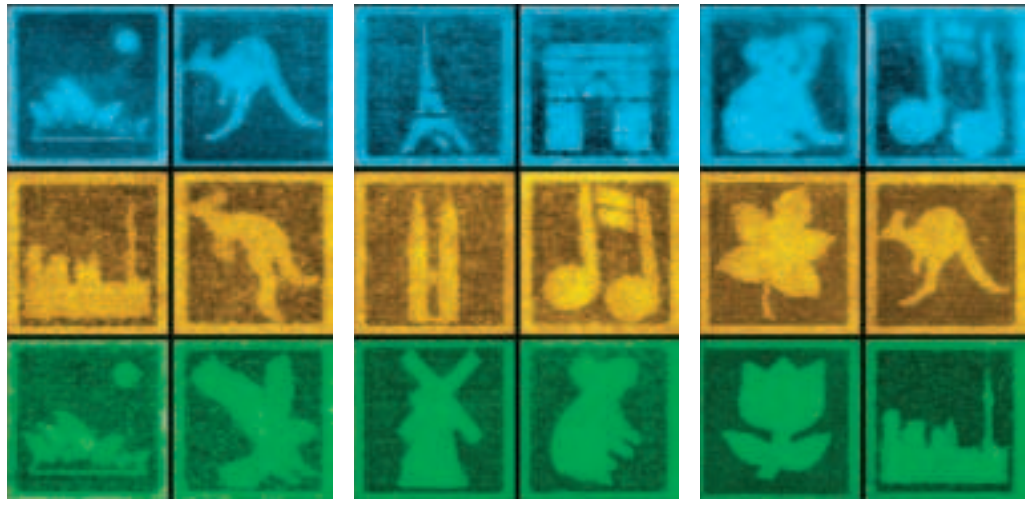
Results: Researchers at the University of Waterloo in Ontario have demonstrated that a new nanostructured cathode material for rechargeable lithium-sulfur batteries can store three times as much energy as the cathodes in lithium-ion batteries on

the market. The new batteries retained this ability to store energy when repeatedly charged and discharged completely over the course of 10 hours.

Why it matters: Lithium-sulfur batteries could store a lot of energy, making them attractive for portable electronics and electric cars. But the low electrical conductivity of sulfur has limited how easily they can be charged and discharged without losing much of their energy-storage capacity, and rapid electrochemical degradation has limited their useful lifetime. The new electrode structure largely overcomes these problems, allowing the batteries to be charged and discharged repeatedly at useful rates while retaining about 80 percent of their theoretical storage capacity.

Methods: The researchers created a material made of regularly spaced nanoscale carbon rods. Then they applied molten sulfur, which was sucked in between the closely packed rods by capillary action (picture sucking up liquid with a bundle of straws). Since carbon is more conductive than sulfur, it allows charge to flow more freely to and from the sulfur. The structure also helps prevent the electrochemical degradation that results when lithium and sulfur fail to react completely, forming intermediate reaction products called polysulfides. The incomplete reaction limits the energy storage of the battery, and the polysulfides can accumulate, further degrading the battery's performance. The tightly packed rods trap polysulfides until the reaction between lithium and sulfur is complete. A polymer coating on the rods helps keep the polysulfides in place.

Next steps: The researchers are developing ways to further improve the stability of the electrode to increase the number of times a battery using it can be recharged. They're also devising ways to manufacture the necessary nanostructures at large scales.



EIGHTEEN IN ONE
Each cluster of six images was recorded to a separate layer of a new material, using combinations of three colors and two polarizations of laser light.

Compact Memory

LIGHT-SENSITIVE MATERIAL COULD HOLD MULTIPLE BITS OF DATA IN THE SAME AREA

SOURCE: "FIVE-DIMENSIONAL OPTICAL RECORDING MEDIATED BY SURFACE PLASMONS IN GOLD NANORODS"
James W. M. Chon et al.
Nature 459: 410–413

Results: Researchers at Swinburne University of Technology in Australia have developed a light-responsive material that can store data at a density of over 1,000 gigabytes per cubic centimeter. It is made up of 10 layers of gold nanoparticles that change shape depending on the color and polarization of light shined on them, a property that makes it possible to store more than one bit of information in a given region of the material.

Why it matters: The material can store far more data than Blu-ray discs, the highest-density optical storage technology on the market today. Each of those discs can store only 50 gigabytes (about 4.6 gigabytes per square centimeter).

Methods: To store multiple bits of information in a single region, researchers irradiate the region with laser light in different combinations of colors and polarizations. Each combination creates a distinct change in the gold nanoparticles that can be read by shining another laser on the region and measuring the reflected light. The researchers engineered particles that respond to yellow, blue, and green light, exploiting the fact that nanoparticles absorb different colors depending on their size. To ensure that the particles respond to different polarizations, the researchers made them rod-shaped. When the light's polarization is aligned with the rods' long axis, they absorb more light, causing the rods to change shape more than if the polarization is not thus aligned. Data can be written separately to different layers of the material, further increasing the amount of data that can be stored in a given area.

Next steps: The researchers will work with Samsung and other companies to engineer data-storage devices based on the new material. TR

NATURE, 2009

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www.technologyreview.com/emtech/09

Nanotech Europe 2009
September 28-30, 2009
Berlin, Germany
http://www.nanotech.net/

2009 Medical Innovation Summit
October 5-7, 2009
Cleveland, OH
www.clevelandclinic.org/innovations/summit

Optimizing Innovation 2009
October 21-22, 2009
New York, NY
http://www.connecting-group.com/Web/EventOverview.aspx?Identificador=6

One Small Step for Science?

THE CELEBRATION OF THE APOLLO 11 ANNIVERSARY RENEWS THE DEBATE OVER THE SCIENTIFIC VALUE OF MANNED SPACE EXPLORATION

By MATT MAHONEY

This summer, as the world looked back 40 years to the day man first landed on the moon, many were also looking forward and wondering when he would return. There has not been a lunar landing since 1972, and as the glories of the Apollo 11 mission were recalled—the audacity of taking a walk on the moon, mainly to show that it could be done at all—there was a call for renewed commitment to manned space exploration. But critics question why we would make such an enormous investment again when almost all our scientific objectives can be met with unmanned rockets and rovers.

This is not a new debate, of course. Forty years ago, in the issue immediately following the successful lunar landing, *Technology Review* devoted two pages to a dispatch from the legendary journalist Victor Cohn detailing a contentious and surprisingly public tussle between scientists and NASA officials in what should have been the agency's finest hour.

The inquiring scientist—to the lovers and leaders of America's space program—is a kind of anointed hitchhiker. You can't fly without him, but you keep him in the back seat.

This became abrasively apparent last summer when, at the height of the success of Apollo 11, a set of key scientists' resignations were received by the National Aeronautics and Space Administration. At the same time, the very lunar scientists who were so thrilled to get lunar samples were complaining sadly that "N.A.S.A.'s glad enough to say a mission is 'for science.' But as far as really doing science—'Sure, they say, take too much time, if, if, if.' In other words, for the flight planners and engineers, getting there and back is the big job. They don't see science playing more than a secondary role, which can be dropped when it gets in the way of a mission."...

Ever since Apollo 11—among other things, certainly a very expensive geological field expedition—there have been pointed symbols of scientists' lowly position in the N.A.S.A. pecking order. More than a week after the landing, Dr. Shoemaker—PI for all lunar geology and rock collecting—still had not officially received any of the photos taken on the moon, though he was supposed to figure out precisely where the rocks were picked up. His group was 14th on the priority list, far below the press.

Dr. Shoemaker got his first photos from Jules Bergman, ABC science editor, and with this and other information he was able to tell the mission controllers just where the spacecraft had landed—an unexpected dividend; the rather hairy landing had left N.A.S.A. mappers puzzled.

(For a fresh look at the photos NASA used to plan the Apollo missions, see "Surface Restoration," p. 34.)

Shoemaker himself would soon leave NASA, convinced that the Apollo project would never achieve its scientific objectives. A longtime advocate for the space program, he now became a prominent critic, complaining that NASA engineers saw the lunar landing as an end in itself rather than as the beginning of the agency's true mission. "We are now," Shoemaker wrote in October of 1969, "in the embarrassing position of having a system that is very good for getting to the moon and getting back, and difficult to use for anything else."

NASA engineers may have objected that getting humans safely to the moon and back was not as trivial or incidental an accomplishment as Shoemaker and others were making it out to be. But the public too, then as now, was more interested in the journey than in the results. All the same, in the end it may have been the disgruntled scientists who saw the future of space exploration more clearly.

SAFE RETURN Neil Armstrong and Buzz Aldrin head back up to the Apollo 11 command module, manned by Michael Collins, after 22 hours on the moon.

NASA

"The vehicle everyone wants," says one scientist, "is an automated vehicle, to be left behind on one flight, sent on a TV-guided traverse with an automatic scoop to pick up samples, then sent to a point to meet astronauts on the next trip." Neither this concept nor a simpler one is yet "in the program." One well-informed scientist says, "It's another case of scientific priorities and budgeting always coming last." TR

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